JANUARY 1955

Journal
of
The Franklin Institute

1826

1955

Reminiscences
WALTER A. R. PERTUCH

Shear Modulus and Viscosity Relations in Plastic Materials
W. F. G. SWANN

Infrared Measurements, Past and Present
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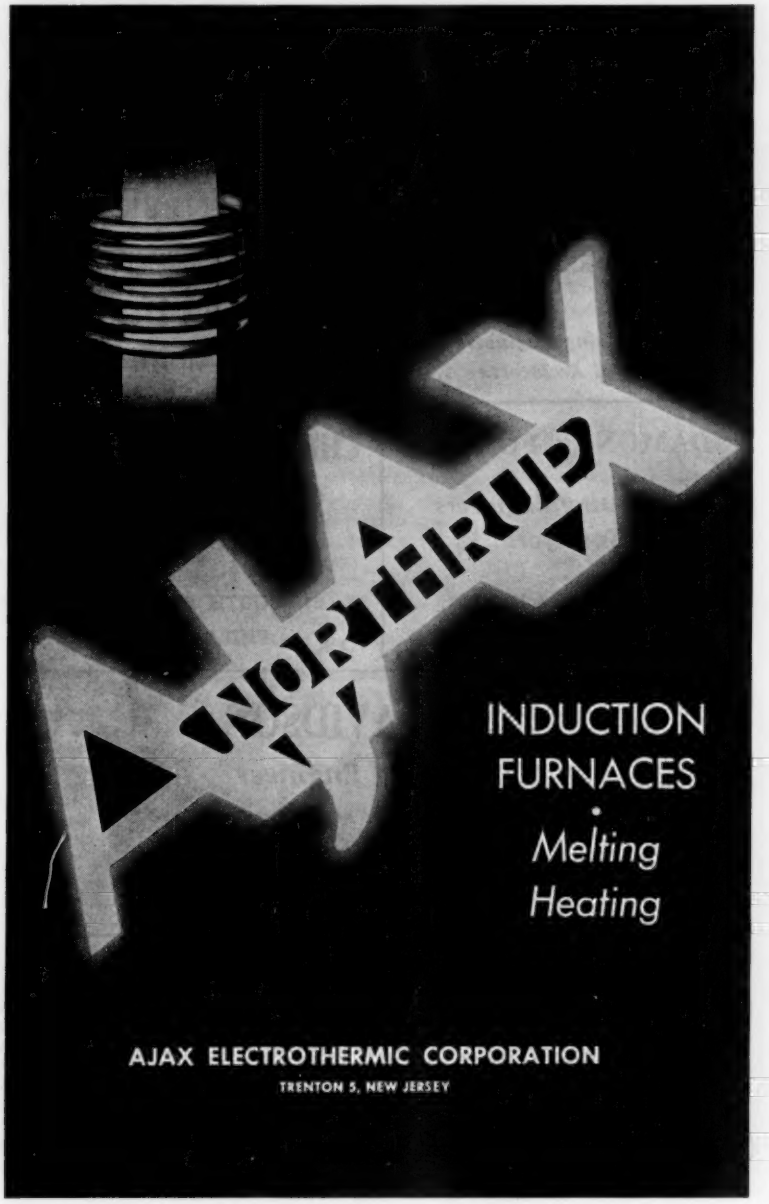
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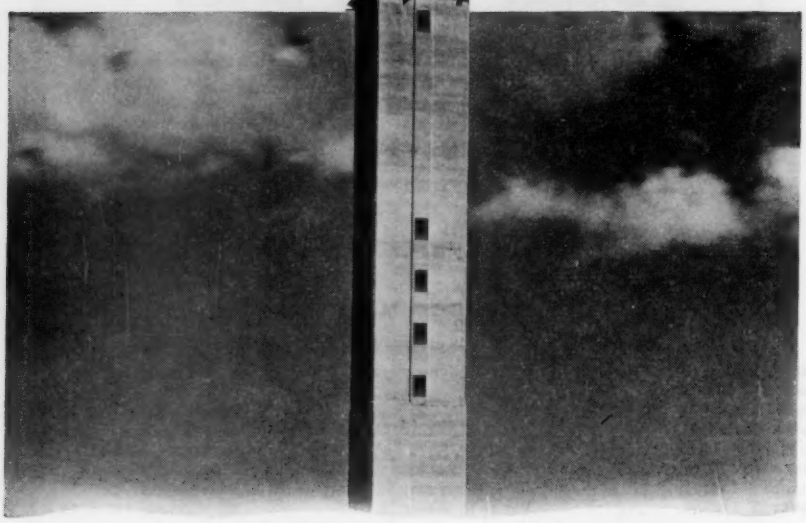

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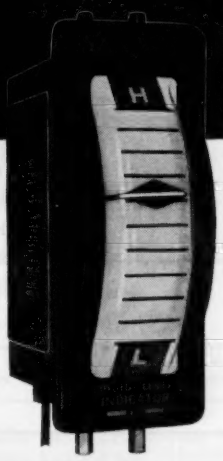

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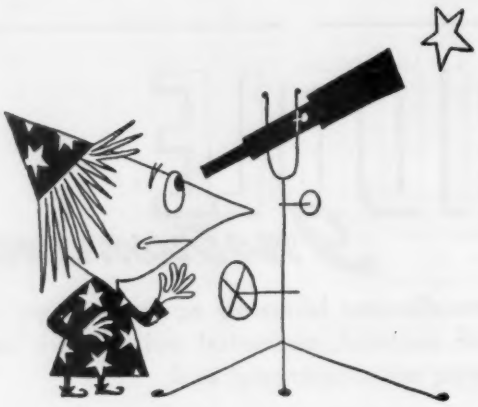

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Vol. 259 JANUARY, 1955 No. 1

REMINISCENCES *

BY

WALTER A. R. PERTUCH [1]

I suppose it would be rather difficult for most of us to remember the many events that occurred fifty years ago. I am in such a position this evening. I do recall that I first saw The Franklin Institute on September 12, 1904, the day I started on what I still think is the best job in the world.

I had spent the summer of that year trying to be a farmer at the country home of Dr. Wahl, who was then Secretary of the Institute. His place of 25 acres was near Doylestown and he commuted to the Institute every day. On weekends there were always groups of members of the Institute up for a visit, so I made their acquaintance which I cherished for many years. Many of them were officers and committee members, and have long since passed away.

When I first saw the Institute, it appeared to be a very dismal place. Everything was old and run down. Even the building looked tired and weary, but before long I liked this atmosphere and wanted it to stay that way. On the first floor there were two store rooms filled with books, and also the lecture hall. On the second floor were the library stacks, reading room, Secretary's office, Actuary's office, and the Board of Managers' meeting room. On the third floor were the school rooms.

Everywhere you looked were books, magazines and dust. There were two telephones in the building—a Bell and a Keystone. When I started as errand boy, by the way, I was chased all over the city. I think they had stopped using the 'phones because they were pay stations.

* Address delivered at the Stated Meeting of the Institute, November 17, 1954. At this meeting Mr. Pertuch was presented with a certificate of Honorary Membership in the Institute, in recognition of his fifty years of service on the Institute staff.

[1] Librarian, The Franklin Institute, Philadelphia, Pa.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

On the day I arrived, there was a meeting of the Committee on Library. I do not think any of the Committee members looked me over—I think they just took me for granted. I made the eighth member of the Institute family: the Secretary, the Actuary, the Librarian, a library assistant, a janitor of some sort, and two typists—a man and a woman. There were only two old, broken-down typewriters, so we could not have any more typists.

In my travels, I collected the five or six morning newspapers published. The *North American* was published on Broad Street, so we did not always have a daily copy of it, since this was quite a walk. The publishers gave the Institute free copies. I carried the mail to and from the Post Office, carried JOURNAL proofs to the authors and printers, and did many similar jobs. In my spare time I browsed around in the Library and learned the titles of many of the books and magazines.

The errand-boy job lasted four years, and many times I was so tired that I wanted to sit down in one of the Morris chairs we had in the reading room, but unfortunately they were always occupied. In the Managers' meeting room there was a couch under the stairs, and one day I did manage to crawl on it and fell asleep. When I woke up, I found Mr. Levy, who was Vice-President of the Institute, asleep along side of me. As I could not climb over the Vice-President of the Institute, I had to stay there for three more hours. I can still see the Librarian's face, all worried, every time he looked in on us.

The Institute had quite a few financial setbacks in the days before I arrived. Although I did not know anything about the financial condition, I was always happy when I received my $2.50 weekly wages on Friday. There were only three times that I was disappointed. On each of these occasions there were no funds in the cash drawer and I did not get my pay; but somehow I was able to carry on. In those days a little money went a long way, and I stretched it out longer by walking to work and home again, even though it meant an hour each way. From the annual report I noted that the Institute had $345 in cash on hand January 1904, and in January 1905, $2200 was listed as on hand. Someone else must have noticed that there was this vast sum of money on hand, for a move was made to give me a raise of fifty cents a week. There was quite a battle over my raise, for the Library Committee said they could not afford this out of their budget. It was finally settled by the Actuary, who gave it to me from the general funds. This was good news to me and it looked as though the Institute were prospering. From then on, every once in a while, I received a raise, and when I was made Assistant Librarian, and no longer errand boy, I was sailing along very nicely on $70 a month. I was then notified that I was to get raised to $85 per month, but when I received my pay, I was five dollars short. So we started all over again with the money argument. At the Library Committee meeting it was decided to give me $80, but one of the

members who was hard of hearing told me that I was to get $85, so after another battle royal, I received the $85. I was very happy, because both the Institute and I were becoming very prosperous.

The main activities that had been started in the early days of the Institute were continued. These were the lectures and meetings, the schools, the Library, the JOURNAL and the work of the Science and Arts Committee. The Board of Managers' meeting was held once a month in the back room on the second floor. It was always very interesting to me to see this odd assortment of gentlemen come in for their monthly meeting. One of the Managers, Washington Jones, who had lost his hearing many years before, attended the meetings very regularly. He would sit through the meeting, not hearing a thing, and would always be the first one to leave after the meeting was adjourned. On the day of the Board meeting, we had to chase around and find 25 chairs, so the reading room looked rather empty while the Managers were meeting. Every time I picked up a chair, I found some part of it needed gluing.

The election of Managers and Officers was held on the third Wednesday of January each year. A dozen members were appointed as tellers and the election was held between 4 and 8 o'clock. The members came to the Institute to cast their ballots. There was always a group of members downstairs electioneering. When there was a lull in the voting, I went across the street to Kelly's Oyster House and brought over platters of fried oysters and beer for the tellers. I had some of the oysters, but the tellers would not let me have any beer!

The Institute meeting was held every third Wednesday and section meetings were held every Thursday for the membership. At these meetings many new subjects were presented, and although I was present, pushing the slides in the lantern, I did not pay much attention to what was said. I was always busy trying to keep the old lantern lit. This job was in my hands for 29 years. The lantern was an old hand-fed carbon one. When the lecturer asked for a slide, I would pull the house-light switch and everyone would sit in the dark until I got the lantern going. There was no heat in the lecture hall, except from a large pot-bellied stove in the corner of the hall. During many of the meetings, the janitor had to fill up the stove, which caused all business of the meeting to stop until he again disappeared. This stove was set up in a sand pit so the floor of the lecture hall would not burn.

The lecturer, many times a perfect stranger, would arrive on his appointed day and announce that he was supposed to lecture. Since I was then handy man around the Institute, I helped him set up his apparatus and often helped with his experiments during the lecture. One of the lecturers had a rather heavy model of a monorail car. To use it, a steel cable had to be stretched across the hall. We fastened the cable to the window sill but that did not hold, so we ran the cable out the window and fastened the end to the fire escape, which held good and tight. The

lecturer wanted me to ride the car during the lecture, but I still did not trust it.

At the section meetings most of the papers were read by different members of the sections. After each of these meetings, certain groups of members would go to a nearby taproom and continue the discussion. At one of the meetings an electric typewriter was displayed for writing letters from a stencil and a group of pretty girls typed to show their speed on the Underwood machine. At another meeting, rapid photography was demonstrated. Chickens were let loose; men jumped over tables; and the audience had a good time while they were photographed. The negative was developed and then shown in the lantern within a few minutes. At another meeting I helped Bakeland cook his product, Bakelite. This was before it was commercialized.

The automatic dial telephone was explained at another meeting. The main station was in the lecture hall and other 'phones were scattered around the building. I was "Chicago" up in the Library.

There was also a lecture on electrical surgical instruments, illustrated with motion picture films. It was quite gruesome and when the lights went up again, quite a few of the audience were out in the front hall with sickly looks on their faces. The motion picture machine was a suitcase type and at the time it did not work properly. On that night, something went wrong and the film would not rewind, so I got out of the tin booth and let the film go all over the floor. I am glad there was no fire.

Many new inventions and talks on new subjects were presented by world-famous scientists. At the different Institute meetings, medals were presented to persons who had been honored by the Institute on the recommendation of the Committee on Science and the Arts. Later, all awards were presented at the Medal Day meetings. At one of the Medal Day meetings, a paper from one of the Franklin Medalists was read by Dr. Hoadley. I had to stand beside him to show certain mathematical formulas made on 10×12 cards. As he gave me a signal, I was to show the next card. There were twenty-two of them and when the meeting was over, Dr. Hoadley told me that I had shown every one of them upside down, but I think that he was the only person who really noticed it. I had to make these cards and since the paper did not arrive until the afternoon before Medal Day, I had to work all night to get them finished. Although I did not get any sleep, I am sure my mathematics was correct!

The first public demonstration of transcontinental telephony was given in the lecture room. Each chair was supplied with a telephone receiver so those present were able to listen to the chairman's conversation with persons in San Francisco. We gave three demonstrations daily for two days. When each showing was over, we let the people out the back way, since the front hall was filled up.

The delightful Christmas Week Lectures were started. Special lectures were given from time to time for a duration of days. Occasionally, anniversary exhibitions were held, with exhibits in different parts of the building.

The Committee on Science and the Arts always held their monthly meeting in the lecture hall. They were a very industrious and quiet working committee. Many of the members gave much of their time to the work of the Committee.

The editing of the JOURNAL was in the hands of the Secretary, but I also had a hand in keeping it going. I had to take proofs to the printer, and some to the authors of papers. When the JOURNAL was printed, I carried the copies from the printer's to the Institute, wrapped them for mailing, and then took them to the Post Office. Later we changed printers and the JOURNAL was printed in West Chester. Fortunately, I did not have to walk down there with the proofs. In 1911 another change was made and the JOURNAL was again printed in Philadelphia. Dr. Wahl passed away in 1909, so Mr. Rigling, Librarian, and I took over the work on the JOURNAL. I found it very interesting, but I recall that many times we both fell asleep over reading the proofs. We both continued on this job for many years.

The schools of the Institute were a very important part of the activities. They were open three nights a week and attended by many men and a few women who generally worked during the day. There were about 500 pupils each session and the schools were continued for 99 years, up to April, 1923. After the school closed, all of the models were gathered up and placed on the school desks, and the third floor became a museum. The course in naval architecture was very important, since there was no other school teaching this course in the country. Each fall, I would travel around in an open carriage to the industrial plants and distribute circulars describing the schools. The school rooms were on the third floor and the only change that had been made in them since the Institute started was to change the lighting. Since the janitor disappeared around five o'clock, I took over the job of opening and closing the school rooms and also saw that the students were warm enough during the winter. The school always had a very high standing and some of the "boys" are now members of the Institute and still active in business. An alumni association was formed while the school was in session. I became friends with many of the students and when we had a slim attendance for a lecture, I would go up to the school and get some of the boys to come down to help fill up the lecture hall. Most of the students were men. A few women studied free-hand drawing. There was one lady who took up mechanical drawing with her brother, because she didn't want to sit home alone.

In a short time, the Library became the most important part of the Institute to me. The Library staff consisted of Mr. Rigling, Librarian,

a young man as an assistant, and myself as errand boy and handy man. I saw that there were many things that needed attention, so I pitched in and before long I had plenty of work on my hands.

I made friends with many members, with the exception of two who wrote letters of complaint about me. One letter stated that every time I opened my mouth to yawn, the member had to hold on to the table so that he would not fall down my throat. Working from 9 o'clock in the morning until 10 o'clock at night, four days in a row, made me tired, and I suppose that I was half asleep on my feet most of the time.

Some of the members paid us daily visits and I would attend to their personal wants, such as getting coffee and sandwiches for them. One daily visitor always had his own special milk shake with him. After enjoying his drink, he would take a tablet for his digestion and then fall asleep. Once I took his little bottle of pills to try an experiment while he was napping. After filling the bottle with water, I put it out on the fire escape and then forgot all about it. All of a sudden there was an explosion and a pane of glass was broken. The sleeping member woke up and made for the door. Mr. Rigling thought a bird had flown against the glass and broken it. I never told him what really happened.

Our work in the Library was regulated by the Library Committee. For many years the same gentlemen served on this Committee. The library assistant resigned in 1906, and Mr. Rigling and I had to run the Library without extra help. After trying out several boys during the following year, we succeeded in finding a good lad, and he proved to be of much help to us. We had one lad with us for about a week. He was interested in Wild West stories, so we thought that we would cure him. He always came in pretty early, so one morning a member and I waited for him behind the door. The member had a revolver with blanks, and I had a mail bag. When the lad arrived in the dark room, I threw the bag over his head and the gun went off several times. He was so scared that he ran down the stairs and that was the last that we ever saw of him. We also secured an elderly lady for book cataloguing. She was very good on the job, but often fell asleep. I soon found out that I had another job on hand trying to keep her awake all day. She finally gave up and we found another cataloguer, who stayed on the job for 25 years and never fell asleep.

In 1904 the Library contained 50,000 volumes, a large collection of pamphlets, and many tons of unbound periodicals and patents. This material was jammed in the book stack and in the cases around the reading room. Some of the books were catalogued in the decimal system and the rest designated in cases 1, 2, 3, and so on. The location of one set of books was marked on the card, "top W.C." and I never could find them. There was a little room built in the corner of the reading room and one day I happened to glance up and saw several books through the dust that had accumulated during the many past years. I borrowed

a ladder and when I climbed up I found the missing set of books. This was "top W.C." With the stack filled, more space was needed, so for a year we carted books and magazines up to the third floor school rooms. They were placed around the sides of the rooms and under the desks. This meant many daily trips to the third floor without elevator service. In 1911 the cellar was cleaned up and shelves were built to take care of the overflow. The floor of the cellar was dirt with a center brick walk. After the magazines were down there, we found rats having a good time eating the glue off the backs of these magazines. The management bought me a .22 rifle and I kept it handy in the cellar to shoot these visitors.

I told a newspaper reporter about the rats eating our magazines and he wrote a story for his paper, mentioning that the rats would take a magazine from a pile and, after eating the glue off the back, would place the magazine back in the proper pile. They were known as The Franklin Institute "scientific rats."

We also had at different times, two dogs and a cat, but they were scared of the rats and spent most of their time in the boiler room sleeping. Later the cellar was covered with a wooden floor and our visitors disappeared.

Spreading the Library all over the building gave us much more room, but then the family got larger and we had to give up the two front store rooms on the first floor. We started to move and crowd the other parts of the building. The Actuary moved downstairs into one room and the Science and Arts Committee to the other room. From then on, it was up and down all day long. We were very crowded and to this day I do not know how we ever managed. The reading room was fenced off, one part for members and the other part for non-members. It was crowded with book cases and racks for periodicals. The lighting was from two arc lights and I had to climb up every day to change the carbons. Twice while I was changing the carbon, I dropped the large white globe from the lamp. One time I dropped it on a table where a member was reading and he was so surprised that he fell under the table and the chair he was sitting on completely collapsed.

In 1912 the lighting was changed and the building received a coat of paint. The reading room also contained five tables for the readers and a lot of old chairs which were "on their last legs." By this time we had a good janitor and the Library was only open two nights a week. The janitor took over the opening and closing of the schools and also the heating.

The heating system was pretty worn out, like I felt most of the time, and one day it did give out. In 1874 a Board committee had been appointed to make suggestions for heating the building and ventilating the lecture hall. Somewhere they had found $2000 and a 33-tube boiler had been installed in 1876. On the day the boiler finally gave up, one

of the tubes had gone, so we sent out for a boiler man. Since there was a lecture that night, and the school was to be open, we had to have heat. I was the smallest person around, so I was pushed inside the boiler to seal the broken tube. The job was done and we had heat that night.

One day the janitor was tired and crawled in the coal bin and fell asleep. He had been putting water in the boiler but forgot to turn off the valve. I was up in the reading room with one member present, when all of a sudden I noticed him sitting and reading with his umbrella raised. Then I noticed water was dripping down from the ceiling. I went up to the third floor and found the place flooded. The radiators had taken all they could. When I got down to the cellar, I found the janitor asleep, the fire out, and a regular fountain coming out of the safety valve. I turned off the water, woke the janitor, and started him mopping up while I built a new fire. There was no school that night.

By this time, I was Assistant Librarian and Superintendent of the Building, so when I could spare time from the Library, I was carpenter, plumber, electrician and roofer. Throughout all of this daily excitement, we had many famous people visit the Institute, but they never knew of the battle we had to keep the place in shape.

The lecture hall, containing 300 chairs, was in pretty good shape by now, with the ventilating system of 1876 working and new heating system installed. That section of the city had been changed over to alternating current so we also had a new modern lantern. The chairs were very uncomfortable, but no one complained since at many of the lectures some of the people had to sit on the floor when we were crowded. There were times when they were jammed out into the hallway and I had to be lifted up over people to get to the lantern. The lectures were very interesting and many experiments were presented there for the first time.

We were never short of company. Members came in to the Library during the day and there were always plenty of people present for the lectures. Occasionally we had visitors who had the wrong address. There was a home for curing drunkards at Ninth and Locust Streets, called the Franklin Home. When these visitors came to the Institute, some of them could no longer navigate and had to be carried out by the police. One of these special visitors was a teamster who formerly had an office in the front cellar of the Institute. Although he no longer had his office there, it seemed that the Institute was the only place he could remember when he had a little too much. I always took good care of him until he slept it off.

The First World War brought some changes in our activities. We had fewer lectures because many of the members were in service. A school for wireless was established, with classes every evening in the reading room.

I was called in 1918, but I was returned after two weeks. Many of

the older members kept us company and when we had the heatless Mondays, the Institute was closed. Some members insisted on coming in on those days, so I put them in the side office were there was a gas grate to keep them warm, for there was no heat in the rest of the building. Just a happy family!

In 1924 we celebrated our 100th anniversary. The activities lasted for a week and we had representatives from other societies and industries from all over the world.

Some time after the anniversary, a move was made to build a new home, and it was not many years after that that we found ourselves in this large home and memorial to Franklin. I hated to leave the old building, and I believe that I was the last one to move out. Everyone was gone, but I still had my Library with me, so I started to move, and in eight and a half weeks the Library was safely placed in our new building.

Every nook and corner of the old building was very dear to me. I spent many days and nights in the old building, even when it was closed. I slept there many nights and when the scrubwoman came in at 6:30, she gave me a cup of tea.

There was always plenty of interesting work to be done and I was having a good time. One Sunday a paper warehouse in back of the Institute caught fire. Our alley at the back of the building was full of smoke, so I opened the back door for the firemen who had been overcome by smoke. They were laid on the lecture room floor, where the doctors worked over them. While the doors were open, all the cats in the neighborhood came in out of the smoke. It was not until the next day that I finally got rid of them. The fire lasted well into the night, so I stayed and slept with the cats.

Although putting in long hours—about 74 a week—I still had some time on my hands and occasionally got into some mischief. I am sure that I was quite a worry to my boss at times. We had some old chemicals stored in a side room off the lecture hall, so I tried to do some experiments. I found some bars of metallic sodium and placed them on the ground out in the side alley, by the lecture hall. Then I climbed up the fire escape and poured a bucket of water down on the sodium. All of a sudden there was an explosion. Everyone in the building came running down the stairs and I ran up the fire escape, over the roof, down the other side of the building, and when I caught up with the rest of the crowd, I asked what had happened. No one knew. After that, I was more careful with my experiments.

We still kept open on two nights during the week and after I came back from my short war venture, I occasionally had a day's vacation. I also tried my hand at attending night classes in a business school, but they told me that I could sleep just as well at home.

No matter what happened at the Institute, I always seemed to have

my hand in it. The heating system always needed attention, the roof leaked and the electric wiring went wrong. The boiler finally gave up completely and 33 new tubes were put in by a professional plumber. With these new additions, it lasted until we moved out. I still went out on special errands collecting gifts of books from members' houses after they had passed on. I even collected a pile of wood shelving from an office building at Broad and Chestnut Streets, which came in handy for shelves in our cellar. This job took two nights and a day, with the help of two extra men and a horse and wagon.

Mr. Howson, Vice-President of the Institute, moved from the tenth floor of a building on South Penn Square. As there was a lot of good shelving in his office, he suggested that we take it down to the Institute. We spent a whole day ripping down the shelves and found many boards 16 feet long. This lumber had to be moved out at night and to get it down to the street we had to stand it on end on top of the passenger elevators. It was then piled against the side of the building until the next night, and then moved down to the Institute. When we moved to this new building, some of this same lumber came up with us.

All this extra work ceased around 1920, when the family became larger and we had the proper help to take care of it. I stuck to library work and helped during the lectures. The extra library help changed so often that I have completely forgotten many of the people who were on the staff. Time will not permit me to mention many of the officers and managers that I served under, or the many members that I came to know. Some of those members and committee members that are serving on the same committees, and also some of the staff that spent time down in the old building; are still active in the Institute.

I have endeavored to give you a picture of some of the events that have occurred in the many past years. To me it has been a wonderful life and I feel highly honored that I have had the privilege of serving the Institute for all these years.

SHEAR MODULUS AND VISCOSITY RELATIONS IN PLASTIC MATERIALS *

BY

W. F. G. SWANN [1]

The simplest relation between stress S, strain σ, and rate of change of strain σ' is given by

$$S = k_0\sigma + \eta_0\sigma', \tag{1}$$

where k_0, the shear modulus of elasticity, and η_0, the viscosity, are absolute constants. We here neglect inertia considerations.

For a sinusoidal relation between σ and t, *viz.*

$$\sigma = \sigma_0 \sin pt \tag{2}$$

the strain assumes the form

$$S = S_0 \sin (pt + \psi), \tag{3}$$

where $S_0 = \sigma_0(k_0^2 + \eta_0^2p^2)^{\frac{1}{2}}$.

Equations 2 and 3 lead to

$$\eta_0 = \frac{S_0}{\sigma_0 p} \sin \psi; \quad k_0 = \frac{S_0}{\sigma_0} \cos \psi \tag{4}$$

which relations serve to determine η_0 and k_0 in terms of the measured S_0/σ_0 and the measured ψ. Since k_0 and σ_0 are absolute constants, it must, of course, result from experiment in this case, that ψ and S_0 will turn out to be such functions of p as to make the right hand sides of Eqs. 4 independent of p.

Equation 1 is linear in σ and σ'. Now it is possible to conceive of an expression for S which involves not only σ and σ' but all of the higher time derivatives. If we constrain σ to have the form (2), all of the time derivatives will assume forms proportional to σ or σ', with the coefficients depending upon p. Thus, for example, the even derivatives σ'', σ'''', σ'''''', etc., will be of the form $-p^2\sigma$, $p^4\sigma$, $-p^6\sigma$, etc., while the odd derivatives σ''', σ''''', etc., will be of the form $-p^2\sigma'$, $p^4\sigma'$, etc.

* A digest of this paper was presented as a discussion to Dr. Wladimir Phillipoff's paper entitled: "Further Dynamical Investigations on Polymers" read before the Society of Rheology at the Hotel New Yorker in New York, N. Y., on October 31, 1953. This discussion is published in the *Journal of Applied Physics*, Vol. 25, pp. 1108–1109 (1954).

[1] Director of the Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.; and a Senior Staff Advisor for The Franklin Institute Laboratories for Research and Development, Philadelphia, Pa.

If the general stress-strain relation, applicable to all forms of dependence of σ on time, is of the form

$$S = A_0\sigma + A_1\sigma' + A_2\sigma'' + \cdots,$$

where the A's are functions of *ratios* of even time derivatives or ratios of odd time derivatives, then, for sinusoidal time variations of σ, all of the A's will become functions of p. Moreover, every even time derivative like $d^{2n}\sigma/dt^{2n}$ will degenerate to the form $(-1)^n p^{2n}\sigma$ and every odd derivative like $d^{2n+1}\sigma/dt^{2n+1}$ will degenerate to the form $(-1)^n p^{2n}\sigma'$. Thus, the whole expression for S will, for sinusoidal time variations of σ, degenerate to the form

$$S = k\sigma + \eta\sigma', \tag{5}$$

where k and η are now functions of p. It must be emphasized that only for sinusoidal time variations of σ will the form (5) be assumed. However, when this form is assumed, the solution of (5) will take the form

$$S = S_0 \sin(pt + \varphi), \tag{6}$$

where

$$\eta = \frac{S_0}{\sigma_0 p}\sin\varphi; \quad k = \frac{S_0}{\sigma_0}\cos\varphi. \tag{7}$$

The experimentalist who, having constrained σ to take the form (2), finds the stress S taking the form (6), will be tempted to think that he is dealing with a linear equation of the type (1) characteristic of the general nature of the substance.[2] He will use the expressions (7) to calculate k and η, and may regard *them* as constants fundamentally characteristic of the material. However, if he repeats his measurements with another frequency, he will find different values for k and η. This invites the rather dubious concept of an elastic constant and a viscosity dependent upon the frequency. Such a concept is highly illogical. An elastic constant or a viscosity dependent upon the velocity (or rather, in this case, σ') is bad enough, although unambiguous in meaning. It simply means that S is expressed as the sum of two terms,

[2] A further invitation to think along these lines comes from plotting S/S_0 against σ/σ_0, in which case, as is well known, and may easily be shown from (2) and (6), we obtain an ellipse, symmetrical about a line at 45° to the two axes. The axes of the ellipse parallel to and perpendicular to this line are, respectively, a and b, where

$$a^2 = \frac{\sin\varphi}{1-\cos\varphi}; \qquad b^2 = \frac{\sin\varphi}{1+\cos\varphi}$$

giving the ratio

$$\frac{a^2}{b^2} = \frac{\left(1+\frac{\eta^2p^2}{k^2}\right)^{\frac{1}{2}}+1}{\left(1+\frac{\eta^2p^2}{k^2}\right)^{\frac{1}{2}}-1}. \tag{8}$$

The difference between equations of the forms (1) and (5) in leading to this result does not reveal itself unless we perform experiments with different frequencies. Then the difference reveals itself in η and k being independent of p when (1) holds and dependent upon p when (5) holds. Even then, dependence upon p can be concealed if η/k is independent of p.

involving σ and σ', but in a non-linear manner. It has unambiguous significance at each instant of time. An equation of the form (5) with k and η functions of p has no fundamental significance at all. In general, the dependence of k and η upon p is only a reflection of a more fundamental dependence upon time derivatives of σ which can only be expressed in terms of p for certain cases where the nature of the particular problem we are concerned with permits. The problem in question is the one which has the particular solution of the fundamental equations which happens to be the sinusoidal solution. For this solution, the ratio of two time derivatives separated by an even number of time differentiations is, *at each instant*, a function of the frequency characteristic of the *solution*. In other words, k and η, unlike k_0 and η_0, are not really constants of the material. They are functions of the substance *and* of the particular solution of the general equations which is the sinusoidal solution. In presenting us with an equation like (5), the sinusoidal solution presents us with a case in which the possibly highly non-linear fundamental equation is able to masquerade in the clothes of a linear form.

Problems of a Non-Sinusoidal Nature

Of course, any general expression for S in terms of σ and its time derivatives must not only be capable of degenerating to the form (5) for the sinusoidal case, but must be capable of expressing the general facts for all types of solution. The case, other than the sinusoidal, in which our interest will here center is that of the steady state in which a constant stress has been applied for a sufficiently long time to bring about a condition in which σ' is constant. This will involve incorporating in the general expression for S terms additional to those which degenerate to the terms of (5) for the sinusoidal case, the said extra terms being such as to provide for the facts of the steady state case. At the same time, it will be necessary to provide for the terms which give rise to the right hand side of the sinusoidal case degenerating to zero for the steady state case.

ATTEMPT AT A FAIRLY GENERAL SOLUTION OF THE PROBLEM

We shall restrict our interest to harmonization of two types of experiments, namely, experiments of the sinusoidal type, in which the experimentalist has found for k and p functions of the form

$$k = f_1(p); \quad \eta = f_2(p) \tag{9}$$

and experiments of what we shall call the steady state type, in which S and σ' finally attain constant values denoted by S_∞ and $(\sigma')_\infty$ and for which the experimentalist has found a relation of the form

$$S_\infty = \sigma' f_3(\sigma')_\infty, \tag{10}$$

where $f_3(\sigma')_\infty$ is an arbitrary function.

In view of the experimental fact that the functional forms $f_3(\sigma')_\infty$ and $f_2(p)$ are related for large values of p, it is necessary that such a relationship shall be permitted by any theory we develop, and it is desirable that it shall be demanded by that theory. However, we shall first consider the more general case where f_1, f_2, and f_3 are all unrelated.

It is to be distinctly understood that we are not about to propose a form of stress-strain relationship to be regarded as a representative of the general realities of the situation. We merely intend to show that relationships *can* be constructed, conforming to (9) and (10). For the determination of the ultimate relationship representative of all the facts, it would be necessary to generalize such expressions as will here be given within the realm of the possibilities suggested so as to fit all types of experiments as well as those concerned in (9) and (10).

A Special Solution of the Problem

While a solution in a form as general as possible is desirable to cover as wide a range of phenomena as possible, a relatively simple solution will meet the needs of our immediate problem.

Let us write[3]

$$S = F_1\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{4}}\right]\sigma'' + F_2\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{4}}\right]\sigma''' + \sigma' f_3(\sigma')\left[1 - \frac{\sigma''\sigma'''}{\sigma'\sigma''''}\right] \quad (11)$$

where F_1 and F_2 are functions to be determined.

For the steady state condition we have

$$S = \sigma' f_3(\sigma') \quad (12)$$

provided that in the limit, as the steady state is approached, $\sigma''\sigma'''/\sigma'\sigma''''$ is zero and F_1 and F_2 are not infinite. We shall discuss the former of these two requirements immediately; the latter will follow naturally in due course.

Of course, on putting S = constant, which corresponds to the condition of our experiment, Eq. 11 becomes a complicated differential equation for σ' and has theoretically the power to tell the story of the variation of σ' with time, including the variation of the limiting ratios of the derivatives. In view of the impracticability of dealing with this differential equation, we shall consider a special variation of σ' with time for large values of t. We shall, in fact, assume[4]

$$\sigma' = \text{const} - \beta e^{-\alpha_1 t}. \quad (13)$$

[3] We could construct an expression involving a smaller number of orders of differentiation than the sixth. However, the form here used tends to avoid certain complications resulting from negative values of the ratio of the derivatives.

[4] The essential characteristic of this expression is that time derivatives, separated in amounts by even orders, have the same sign.

We could, in fact, always create a slight departure of S from a constant value to permit (13) being a solution of the problem. From (13)

$$\sigma'' = \beta\alpha_1 e^{-\alpha_1 t}; \quad \sigma''' = -\beta\alpha_1^2 e^{-\alpha_1 t}; \quad \sigma'''' = \beta\alpha_1^3 e^{-\alpha_1 t}.$$

Thus

$$\frac{\sigma'\sigma''''}{\sigma''\sigma'''} = -\frac{\sigma'\beta\alpha_1^3 e^{-\alpha_1 t}}{\beta^2\alpha_1^3 e^{-2\alpha_1 t}}$$

$$\left|\frac{\sigma'\sigma''''}{\sigma''\sigma'''}\right| = \frac{\sigma'}{\beta} e^{\alpha_1 t} = \infty \text{ when } t = \infty$$

since σ' is finite at $t = \infty$. Thus

$$\frac{\sigma''\sigma'''}{\sigma'\sigma''''} = 0 \text{ at } t = \infty \text{ as desired.}$$

Also, it may be noted for future reference that

$$\frac{\sigma''''}{\sigma''} = \alpha_1^2 \tag{14}$$

at $t = \infty$, and indeed for all times at which (13) applies, and so is finite.

For the sinusoidal case $(\sigma''\sigma'''/\sigma'\sigma'''')$ is obviously unity, so that for this case the term in $f_3(\sigma')$ disappears, and we are left with

$$\begin{aligned} S &= F_1(p)\sigma'' + F_2(p)\sigma''' \\ S &= -p^2F_1(p)\sigma_1 - p^2F_2(p)\sigma'. \end{aligned} \tag{15}$$

Hence, comparing with (9), it is necessary to have

$$\begin{aligned} -p^2F_1(p) &= f_1(p) \\ -p^2F_2(p) &= f_2(p) \end{aligned}$$

$$F_1 = -\frac{f_1(p)}{p^2}; \quad F_2 = -\frac{f_2(p)}{p^2}. \tag{16}$$

Thus possible forms for F_1 and F_2 applicable to the general case and reducing to (16) for the sinusoidal case are

$$\begin{aligned} F_1 &= -\left(\frac{\sigma''}{\sigma''''''}\right)^{\frac{1}{3}} f_1\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{3}}\right]; \\ F_2 &= -\left(\frac{\sigma''}{\sigma''''''}\right)^{\frac{1}{3}} f_2\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{3}}\right] \end{aligned} \tag{17}$$

and our general equation satisfying all the required conditions becomes

$$S = -\left(\frac{\sigma''}{\sigma''''''}\right)^{\frac{1}{3}} f_1\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{3}}\right]\sigma'' - \left(\frac{\sigma''}{\sigma''''''}\right)^{\frac{1}{3}} f_2\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{3}}\right]\sigma''' + \sigma' f_3(\sigma')\left[1 - \frac{\sigma''\sigma'''}{\sigma'\sigma''''}\right]. \tag{18}$$

Since, as we have already demonstrated, for the approach to the steady state symbolized by (12), σ''/σ'''''' is finite, the first two terms of (18) disappear for the steady state if $f_1(\beta)$ and $f_2(\beta)$ are finite when β is finite, and experiment may naturally be expected to reveal this last requirement.

Construction of a Relationship which Demands Similarity Between f_2 and f_3

The experiments of Dr. Wladimir Phillipoff[5] reveal a rather surprising relation between the functions f_2 and f_3, a relation to the effect that if, for large values of p, we consider corresponding steady state conditions with velocities σ' given by $\lambda\sigma' = p$, where λ is a constant, then

$$f_3(\sigma') = f_2(\lambda\sigma') = f_2(p). \tag{19}$$

Such a relationship is permitted by (18) but not demanded by it. It is of interest to see how we can specialize our expression for S so as to demand this relation. All that is necessary is to write $f_2(\sigma'\lambda)$ for $f_2(\sigma')$ in (18).

A rather more elegant expression, leading to the same ultimate endpoint, is

$$S = -\left(\frac{\sigma''}{\sigma''''''}\right)^{\frac{1}{4}} f_1\left[\left(\frac{\sigma''''''}{\sigma''}\right)^{\frac{1}{4}}\right]\sigma'' + f_4\left[\sigma'\left(1 - \frac{\sigma''\sigma'''}{\sigma'\sigma''''}\right)\lambda + \left(\frac{\sigma''''''}{\sigma''} - \alpha_1{}^4\right)^{\frac{1}{4}}\right]\sigma' \tag{20}$$

with the understanding that $f_4(p^4 - \alpha_1{}^4)^{\frac{1}{4}}$ is defined as $f_2(p)$. In this case, for the sinusoidal case we obtain

$$\begin{aligned} S &= f_1(p)\sigma + f_4(p^4 - \alpha_1{}^4)^{\frac{1}{4}}\sigma' \\ &= f_1(p)\sigma + f_2(p)\sigma' \end{aligned}$$

while for the steady state case, we obtain

$$S = f_4(\lambda\sigma')$$

and for large values of $p(= \lambda\sigma')$, $f_4(\lambda\sigma') = f_2(\lambda\sigma')$, as desired.

It will be understood that the expressions considered above do not carry with them any theory as to their origin. Insofar, however, as they fit the facts, they may be taken as suggesting directions which modification of present theory may be expected to assume.

[5] Private communication.

INFRARED MEASUREMENTS, PAST AND PRESENT *

BY

EARLE K. PLYLER [1]

ABSTRACT

The important developments in the field of infrared measurements are traced from 1800 to the present time. Four periods are considered and it is shown that the developments of the last period (1945 to the present time) were brought about by researches which had been carried out previously. The improvements of sources, detectors, optical materials, and electronic amplifiers are discussed.

Infrared measurements have been made for the last one hundred and fifty years, but this field of investigation is still very active with about 600 papers appearing in the scientific journals each year. Infrared measurements are a very valuable tool for the investigation of many problems. While the greatest interest is in the field of chemistry in the analysis of compounds and the determination of molecular structure, many fields, such as physics, geology, biology, and astrophysics, have problems which can be solved by infrared techniques. This discussion will be concerned primarily with the improvements and developments in methods of measurement of infrared radiation, rather than the applications.

The one hundred and fifty years of infrared research may be divided generally into four periods: (1) from the beginning, with the discovery of infrared energy by Herschel, in 1800, to the development of the infrared spectrometer by Pringsheim in 1883; (2) the period from 1883 to 1917 which produced great strides in the qualitative and quantitative analysis of materials; (3) the period from 1917 to 1940 which was characterized by many theoretical advances (it was during this period that the grating spectrometer was first utilized for the measurement of molecular rotation-vibration bands); and (4) the period extending from 1940 to the present time which has seen the development of new prism materials such as CsBr and CsI, which has extended prism measurement out to 50μ, the introduction of radiation detectors such as PbS, PbSe, and PbTe, which have sensitivities up to 1000 times that of the thermocouple, and the building of spectrometers of high resolving power through the use of precision optics.

After the discovery by Herschel of infrared radiation by the rise in the temperature of thermometers, the next development was the

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[1] Chief, Radiometry Section, National Bureau of Standards, Washington, D. C.

discovery of the thermoelectric effect by Seebeck in 1823. Nobili (1829) used this principle in the construction of a bismuth-antimony thermocouple, and for detecting the thermoelectric current he constructed an astatic magnetic galvanometer. In this manner was arranged a detector of radiant energy which could be used as a quantitative measuring instrument. Since the development of this first system there have been many studies on improvements and new types of detectors such as the introduction of bolometers by Langley and the Crookes radiometer.

More sensitive galvanometers were built, and there was a gradual improvement in detection so that more precise measurements could be made. The development of infrared improvements may be considered from the standpoint of sources, detectors, amplifiers, optical systems, and techniques of measurements. These topics will be treated in more detail in the following sections.

SOURCES

Since any heated body emits radiation there are many sources for infrared measurements. In fact the early investigators were able to make very approximate measurements on the transmissive properties of materials, by using as sources various objects, heated to different temperatures. In a number of the early papers the workers would refer to the transparency of a material when measured by luminous radiation and the diathermancy of a material when measured by nonluminous energy. It was by the use of luminous and nonluminous sources that Melloni (1834) first found that rock salt had a high transparency to both types of radiation and was therefore of value for prisms and lenses in the study of infrared radiation. Early experiments directed to the discovery of sources which would radiate high energy in the infrared involved heating solid bodies in a flame. These experiments finally culminated in the discovery of the source known as the Welsbach gas mantle, which owed its large emission to the thorium and cerium oxide within the mantle.

Today we have Nernst glowers, globars, tungsten lamps, carbon arcs, and more recently the Western Union enclosed arcs. This Western Union enclosed arc is very intense in the near infrared, and has been a valuable addition to sources available.

DETECTORS

Since the beginning of infrared measurements the thermocouple or, later, the thermopile, has been one of the standard detectors of radiant energy. Nobili (1829) was soon applying the discovery of Seebeck and published a description of a thermopile containing six junctions of bismuth and antimony. He also had six other junctions which were shielded from the radiation, thus showing that he realized the need for

compensation in order to avoid drift of the recording instrument. There have been many improvements in thermopiles since this early prototype. By using strips of metal of much smaller heat capacity, the rapidity of the response was greatly increased and by placing the junctions in a vacuum, the ambient changes were greatly minimized. New materials have been introduced for the thermocouple junctions and structural changes have been made. By mounting a small strip of the material on two wedges, the time constant has been greatly reduced so that a-c. amplifiers could be used with them.

E. F. Nichols (1897) developed the vane radiometer into a very sensitive detector. He measured very short electromagnetic waves with this detector. Nichols and Tear (1926) were able to detect waves as short as 1 mm. or 1000μ, which went a long way to closing the existing gap between radio waves and infrared radiation. Microwave techniques have recently been developed which make it possible to extend measurements to 880 microns.

In 1911, Rubens and Wood discovered that a mercury-quartz enclosed arc generated very strong infrared radiation in the spectral region of 250 microns. In 1950 McCubbin and Sinton were able to extend these measurements to 550μ. They used a coarse ruled grating for the dispersing element and a Golay cell for the detector. Thus the gap between infrared and microwave measurements has been almost closed by these recent improvements.

Langley (1883) was able to make good measurements with thin strips of platinum in the arm of a Wheatstone bridge, which he called a bolometer. Other metals have been used for bolometers and more recently metallic oxides of high resistance have been used. They are called thermisters and they have been found to be about equal to thermocouples in sensitivity.

The Golay cell was first made about ten years ago and has proved to be a very sensitive detector of infrared radiation. It is in essence a gas thermometer in which the energy slightly changes the position of a reflecting surface which is on a membrane in one end of a cylinder. The radiation is absorbed by a darkened area on a membrane in the other end of the cylinder. By means of a suitable optical system and a photocell, these small movements of the reflecting section are transformed into electrical variations which are amplified and recorded. The Golay cell has a rapid response which allows more rapid modulation of radiation than a thermocouple. In some uses this is of considerable advantage.

Soon after photocells were made for the visible and ultraviolet regions, research was started by Case, Coblentz and Pfund on the possible photoelectric effect of many materials for infrared radiation. The thalofide cell (TlS) resulted from these studies and proved to be very sensitive to radiation to about 1.4μ. Barnes and Fulweiler (1928)

used a thalofide cell for measurements with a grating instrument in the region of 1μ. On account of the high resistance of the cell an electrometer was used instead of a galvanometer for measuring the energy.

Coblentz (1917) studied the photoelectric properties of many materials and found that molybdenite had a photoelectric sensitivity in the near infrared extending to about 2μ. This material made a more sensitive detector than a thermocouple and was used by Coblentz in the measurement of the radiation from the stars. From these early investigations there have been developed the modern PbS, PbSe and PbTe cells.

DETECTING METHODS

Nobili not only made the first thermopile for radiant energy but he also made an astatic magnetic galvanometer for the measuring instrument. In later years galvanometers of good stability were made and, by taking several deflections of the galvanometer for the radiant energy falling on the thermocouple, accurate measurements could be made. This method of measurement was standard until about 30 years ago.

With the development of electronic tubes there was a hope that a system might be devised whereby the potential generated by the thermocouple when exposed to infrared radiation could be amplified and read directly on a meter. This would eliminate the galvanometer with its instability and allow measurements to be made in buildings which were not constructed to reduce the effects of vibrations. This was accomplished many years later by the introduction of the G.M. breaker type amplifier, but before describing this instrument other developments and methods of measurement will be mentioned.

Two difficulties stood in the way of amplifying the current from the thermocouple: (1) the small e.m.f., and (2) the relatively long period of response. These difficulties were clearly recognized by Merritt and Coblentz when they set out to make a measuring instrument other than a galvanometer for infrared detection. To overcome the slowness of response they used a circuit interruptor in the form of movements of the balance wheel of a watch on which was attached a small gold wire for the contact. In order to overcome the difficulty of the small voltage, the interrupted current was fed into a Ford spark coil. By the use of a simple electronic amplifier the current was further enlarged to be read on a meter. They found that they could detect a bonfire 5 miles away, but that in out-of-door use the drift of the instrument was very large. The fact that this work was not published no doubt retarded further developments of this type.

The Mohl thermal relay was based on the principle of using the small deflections of a galvanometer of high stability. A beam of light was focused on the center of a metallic strip at each end of which was joined another metal such that two thermocouples were made with

opposite polarity. The current produced by the thermocouples at the ends of the strip were read by a second galvanometer. Small deflections were increased by a hundred times or more by the Mohl thermal relay. A little later the Mohl thermal relay was replaced by two photocells which were used to increase the deflections of the galvanometer. These methods of detection were of considerable value and brought about a large amount of work with high resolution grating spectrometers. On account of the drift of the zero of the galvanometer it was necessary to reset it from time to time.

In order to avoid the erratic movements of the galvanometer coil which was produced by vibrations of the building, Pfund modulated the radiation falling on the thermocouple at the period of the galvanometer and thus the galvanometer coil would deflect back and forth with a deflection proportional to the energy. Firestone further developed this idea and also removed the drift of the galvanometer zero. His instrument consisted of modulating the beam of radiation falling on the thermocouple so that a galvanometer would deflect periodically. Radiation reflected from the mirror of the galvanometer was focused on a photocell. By means of a suitable amplifying system only changes of the galvanometer mirror were detected and passed to the second galvanometer which in turn oscillated back and forth. By means of a suitable optical system a small beam of light from the mirror of the second galvanometer was focused on a drum of photographic paper. The excursions of the galvanometer which were recorded on the paper thus permitted the keeping of a permanent continuous record of the spectrum of any substance.

The greatest advance in detecting systems was the development of the G.M. amplifier by the General Motors Research Laboratories. This amplifier operated entirely without the use of galvanometers. It removed the trouble of vibrations and made it easier for infrared measurements to be made in industrial laboratories. The amplifier worked on the principle of interrupting the circuit many times a second, and then the current was passed through a transformer of high voltage gain to an amplifier. The instrument had special contacts which operated over long periods of time without need of renewing. Its sturdiness, trouble-free operation, and high sensitivity made it possible to obtain many records of good resolution during a day. With the advent of thermocouples of rapid time response, a-c. amplifiers are now in use, and thus the drift of the zero of the instrument is removed. It should be stated that the development of electronic detecting systems has been one of the major advances in infrared measurements during the last twenty years.

SPECTROMETERS

The early spectrometer of Pringsheim may be considered as the prototype of present day prism instruments. The improvements have

been many. In place of speculum metal or silver films the mirrors now in use have a coating of aluminum which can be evaporated to a very smooth highly reflecting surface. The sharpness of the image on the second spectrometer slit has been greatly improved by using off-axis paraboloidal mirrors, and curved slits have been introduced to offset the curvature of the image which arises from the prism.

From the time of Pringsheim many materials have been found to be suitable for prisms, with good resolution in certain regions of the spectrum. There are now available prisms made of not only sodium chloride, glass and quartz, but also lithium fluoride, calcium fluoride, potassium bromide, thallium bromide-iodide, cesium bromide, and cesium iodide. These materials permit infrared measurements to be made from the visible out to 50 microns.

In the last fifteen years several manufacturers have produced compact, highly efficient instruments. The resolution of these instruments has been increased by the recent Walsh double pass system which causes the prism to be traversed four times instead of twice.

The development of the double beam instrument along the lines described by Hardy and Wright has greatly helped to make the infrared spectrometer an analytical instrument. The instrument automatically records the per cent transmittance, as a function of wavelength or wave number of the substance under investigation. In a few minutes the spectra of a compound can be measured in the range from 2 to 15 microns. The instruments repeat the transmission with such high precision that it is reliable as a quantitative measurement. Another advantage of the double beam spectrometer lies in removing from the recorded chart the spectrum of the atmospheric bands of water vapor and carbon dioxide. Some of the earlier instruments were made free of the detection of atmospheric absorption by enclosing the instrument in a case so that it could be operated in a vacuum. One instrument of this type was designed by Dr. Strong at the University of Michigan. In addition to its being in vacuum, it had controls on the outside for automatic operation. Gratings in place of prisms have been employed in spectrometers for a long time. Rubens made gratings by separating metal wires by the diameter of the wire and was able to measure restrahlen of crystals to 150 microns. Paschen used gratings in high precision measurements of atomic spectra in the infrared region. In 1917 Prof. Randall introduced the combination prism-grating spectrometer for infrared absorption measurements. The grating instruments now in use are similar to those built at the University of Michigan but on account of improvements in components such as the gratings, mirrors and detectors, the modern instruments have much higher resolution.

The infrared region has never had a large number of standards of wavelengths such as available in atomic spectra. The spectrometers

were calibrated by the use of the indices of refraction or by the use of the maxima of an interference pattern. Today many prism spectrometers have a cam which is shaped to give wavelength or wave number readings for different settings of the Littrow mirror. A check on the accuracy of the wavelength scale is made by using absorption bands which have been measured by grating spectrometers. For highest precision the grating spectrometers are calibrated from the fringe system of a Fabry-Perot interferometer. By the use of a two-pen recorder, with one pen recording the fringe system and the other pen recording the absorption spectrum, the absorption lines can be measured to a high precision.

RELATED FIELDS

In this brief resume of the gradual development of methods and instruments in infrared measurements it has been possible to discuss only some of the major achievements. The present discussion is sufficient, however, to show the rapid gains which have been made in the last twenty years. With the announcement of the Raman effect there was a feeling among some scientists that infrared had passed its usefulness as a major tool for the investigation of molecular structure. It was soon found that certain bands were active in the infrared spectrum and others in the Raman spectrum. Thus the Raman observations were a valuable complement to infrared measurements and made possible the complete vibrational analysis of many molecules.

Comparison of Raman and Infrared Frequencies (cm^{-1})

CH_3–C Cl_3	R 342	R 240		
	I 344	I 241		
CH_2Cl–C Cl_3	R 334	R 307	R 242	
	I 332	I 306	I 242	
CH Cl_2–CH Cl_2	R 353	R 325	R 289	R 241
	I 353	I 325	I 289	I 241

More recently with the use of microwave spectra the moments of inertia and the distances between atoms can be measured with very high precision. The microwave measurements seem to have stimulated infrared measurements so that now the accuracy has been greatly increased. In one particular the microwave and the infrared measurements supplement each other. In infrared measurements the wavelength of a line is measured and the frequency of the line is calculated. The microwave measurements are in terms of frequency. The calculated frequency from infrared measurements agree to a high precision with the direct measurements by microwave techniques. Conversely, on the basis that frequency times wavelength is equal to velocity, recent measurements in both the microwave and the infrared spectra

of the molecules HCN and CO have led to determination of the velocity of light. By use of microwave frequencies in conjunction with infrared measurements Rank and his coworkers obtained a value of 299790 km./sec. for HCN and the writer has made a similar set of measurements on CO and obtains a value of 299792 km./sec. These two values are in close agreement with recent determinations which have been made by other methods.

CONCLUSION

The instruments for infrared research are now developed to such a high level that many investigations of molecular structure can be carried out and the properties of large molecules may be determined. The next two decades should be filled with many studies within the important field of molecular structure which is of major interest to physics and chemistry. No doubt within the same period many improvements of instruments will be made.

It should be recognized that in a field so rich in accomplishments one paper can not have completeness. In a bibliography on infrared spectra, being compiled at the National Bureau of Standards, over eleven thousand articles have already been listed, and the number is rapidly growing with about six hundred new papers each year.

With the richness of the literature on the various subjects discussed it would require many pages to cover adequately the references, so they have not been included. References to all the important work completed between 1800 and 1900 can be found under the author's name in the books, Poggendorff, J. C., "Biographisch-Literarisches Handworterbuch zur Geschichte der exacten Wissenschafter," Leipzig, Vols. 1 and 2, 1863, and Vol. 3, 1898. The references to work since that time can be found in *Physics Abstracts* and *Chemical Abstracts*. An interesting article (by W. W. Coblentz) on the early history of infrared spectra was published in 1949 in *The Scientific Monthly*. It is entitled "Early History of Infrared Spectroradiometry."

MICROTRON RESONATORS *

BY

H. F. KAISER [1]

ABSTRACT

The microtron (1)[2] (electron cyclotron) depends upon a cavity resonator for its electron source and for turn acceleration. The geometrical requirements, particularly those pertaining to the electron orbit clearance which such a resonator has to meet in a conventional microtron are discussed for a series of resonator forms. The confocal ellipsoidal-hyperboloidal resonators due to Hansen and Richtmeyer (2) seem to be best in respect to shunt resistance and associated Q. An analytical procedure for determining the parameters for specified accelerator conditions is developed. Resonators which have been developed for X- and K-band microtrons (3) are described.

INTRODUCTION

The microtron is an electron accelerator in which all the particle orbits are cotangential at a point in the acceleration gap of a cavity resonator. For efficient operation this resonator should, in general, have as high a shunt resistance R and associated Q as is permitted by the restrictions imposed by the geometry of the apparatus as related to the orbital conditions.

If the first orbit in the microtron is small, a basic restriction is the diameter of this smallest orbit, which must be somewhat larger than the radius of the resonator which it threads. Since this radius is determined in part, at least, by the radio wavelength λ of operation, it is next of interest to see how the electron orbit radius is related to λ.

Letting E_1 represent the total energy of the electron in the first orbit, C_1 the fraction of a rest mass energy $E_0 (= m_0c^2)$ possessed by the electron in the form of kinetic energy after the first passage through the resonator, the period of the electron in the first orbit is given by

$$T_1 = \frac{2\pi}{Hec} E_1 = \frac{2\pi}{Hec} (1 + C_1)E_0 = MT_0 = M\frac{\lambda}{C}, \qquad (1)$$

where H, e, and c have their customary meanings and M is an integer giving the number of fundamental r.f. periods of length T_0 required for a complete orbit. M must be integral so that the electron may arrive in correct phase for further acceleration, and it is easily shown that C_1 must also be integral or a rational fraction.

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[1] Nucleonics Division, Naval Research Laboratory, Washington, D. C.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

The radius of the electron orbit is given by

$$r_1 = \frac{1}{He}(E_1^2 - E_0^2)^{\frac{1}{2}} = \frac{4}{\pi}\left(\frac{2C_1 + C_1^2}{1 + C_1}\right)^{\frac{1}{2}} \frac{M\lambda}{8} \qquad (2)$$

on eliminating H by means of Eq. 1.

The factor before $M\lambda/8$ has a value near unity. The integer M may have the value 1 only under special conditions. In operating

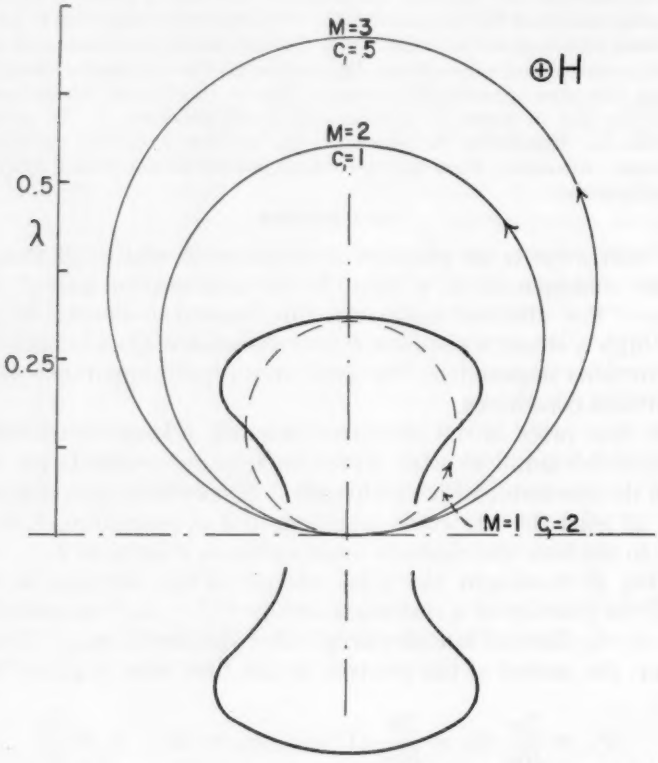

FIG. 1. Microtron resonator cross section in relation to electron first orbits.

microtrons (3, 4, 5) its lowest value is 2 or 3. The first orbit radii corresponding to the values of M from 1 to 4 as encountered in the usual modes of operation, computed from Eq. 2 are given in the table below:

M	1	2	3	4
C_1	2	1	0.5	0.33
$r_1/(\lambda/8)$	1.200	2.204	2.883	3.369

Since the microtron cavity resonator will have a diameter of the order of $\lambda/2$ (or radius $\lambda/4$), the table shows that in all cases the electron orbit diameter is larger than the "$\lambda/4$ minimum" radius of the resonator, and, in principle at least, resonators may be designed for any first orbit possible. Only in the case $M = 1$, $C_1 = 2$ will the design be difficult.

The spatial relationship of the cross section of a typical microtron resonator to the electron orbits mentioned is illustrated in Fig. 1. It is now of interest to determine how cavity resonators of various kinds utilize the area of the orbits threading the resonator. Qualitatively, the larger the resonator that may be employed the larger the Q and associated shunt resistance R_s. While this may have limitations and exceptions the general trend can best be illustrated by referring to Fig. 9 which shows the family of ellipsoidal-hyperboloidal resonators treated by Hansen and Richtmeyer (2). All these resonators have the same resonant wave length but have shapes ranging from a simple sphere and cone resonator through increasing size resonators into long cylindrical resonators as the design parameter σ_0 (ratio of equatorial diameter to interfocal distance) decreases through four orders of magnitude. The curves for $Q\ \delta/\lambda$ and $R_s\ \delta/\lambda$ show that these increase as the volume of the resonator increases, down to a value of $\sigma_0 \sim 0.1$ where the Q reaches a stationary value. For values of σ_0 below this the resonator shapes are unsuited for microtron resonators except when modified by special deformations, as in the case of bent cylinders.

In determining the optimum size of any type of resonator that can be applied in a given orbit specification, it will be useful to give a figure of merit or utilization factor to indicate what fraction of the orbital area is occupied by the resonator cross section. Due to the variety of forms and the complicated way in which Q and R_s depend on cavity form, no strict correlation of this factor with these quantities may be expected.

Before proceeding with the discussion of the hyperboloidal-ellipsoidal resonators, a review of other simpler shapes should be made to illustrate the values of Q and R_s which may be expected from these and also the geometrical peculiarities in regard to resonance which are to be found in them.

I. SPHERE AND CONE TYPE RESONATORS

Resonators of this type, while having the lowest Q and shunt resistance, have the simplest and most easily treated cross sections. The relationship to minimum orbit is shown in Fig. 2. The largest cross section is that for which the three corners determine three points of the orbit circle. For a given orbit radius r_m the radius of the spherical surface is $R = 2r_m \sin\theta$ and since the wavelength condition for resonance is simply $R_{res} = \lambda/4$, the vertex angle of a resonant section is given by $\sin\theta_{res} = \lambda/8r_m$.

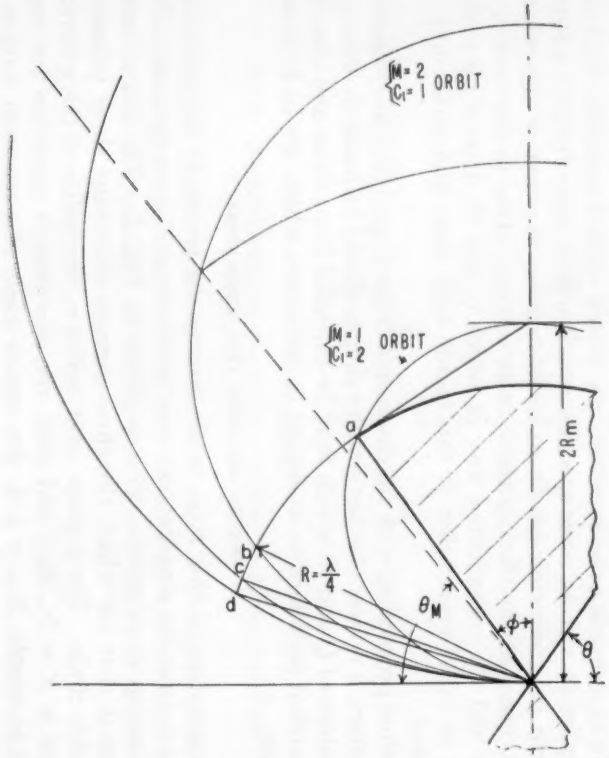

FIG. 2. Sphere and cone resonator cross section and electron first orbits.

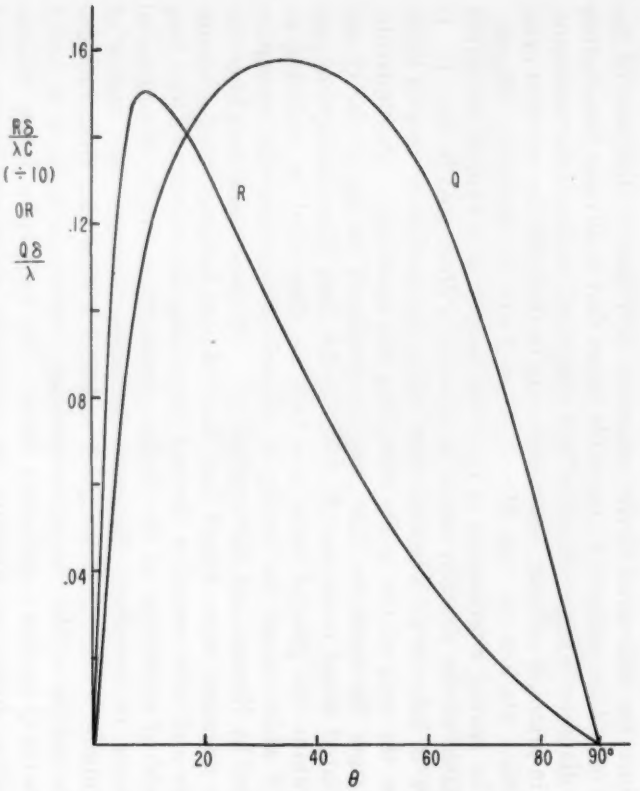

FIG. 3. Q and R_s of sphere and cone resonators as determined by vertex angle (Hansen and Richtmeyer).

The fraction of orbit area occupied by a section of vertex angle θ is given by the utilization factor F, where

$$F = \left(2 - \frac{4\theta}{\pi}\right) \sin^2 \theta. \tag{3}$$

Disregarding for a moment the wavelength condition, the maximum value of F is given by that value of θ satisfying the transcendental equation $\tan \theta = \pi - 2\theta$. It is very nearly 52°51′ (0.922 radian). A resonant section having this vertex angle (Fig. 3) would have a fairly good Q (0.910 Q_{max}) but a relatively low shunt resistance (0.35 $R_{s_{max}}$). For this angle $F_{max} = 0.525$.

From Fig. 2 it is evident that the resonant vertex angle θ_r is near θ_{max} for only one of the possible orbits ($M = 1$, $C_1 = 2$), which is not likely to be realized in practice. The other types of orbits, encountered in operating microtrons ($M = 2$, $C_1 = 1$) ($M = 3$, $C_1 = 0.5$) and so on, determine by their intersections b, c, d, etc., with the circle $R = \lambda/4$, maximum resonant sections for which the vertex angle becomes progressively smaller. From Fig. 3 it is seen that this is attended by an increase in R_s to a maximum near 9° at which the Q is still $\sim Q_{max}$. (The resonator volume increases as the orbital radii increase but the utilization factor F decreases at the same time. This shows that this factor must be restricted in comparing utilization of various kinds of resonator cross sections to those pertaining to the same type of orbit.) It has been shown above that the orbital radius and the wavelength are related directly by

$$r_m = k_1 M \lambda / 8,$$

where k_1 is a function of C_1, and thus the resonant vertex angle θ_{res} is determined by

$$\sin \theta_{res} = \frac{R_{res}}{2r_m} = \frac{1}{k_1 M}, \tag{4}$$

from which

$$F = \left(2 - \frac{4}{\pi} \sin^{-1} (k_1 M)^{-1}\right) (k_1 M)^{-2}. \tag{5}$$

The values of F computed from this for several possible first orbits are tabulated below together with corresponding values of θ_{res}.

M	1	2	3	4	5
C_1	2	1	0.500	0.3333—	0.250
F	0.5145	0.2880	0.1977	0.1426	0.1143
θ_{res}	56°30′	26°50′	21°00′	17°20′	15°10′

As the vertex angle of the cross section decreases, the resonator approaches a sphere as the limit. This form may be used as a microtron resonator if provided with apertures as shown in Fig. 4. An obvious

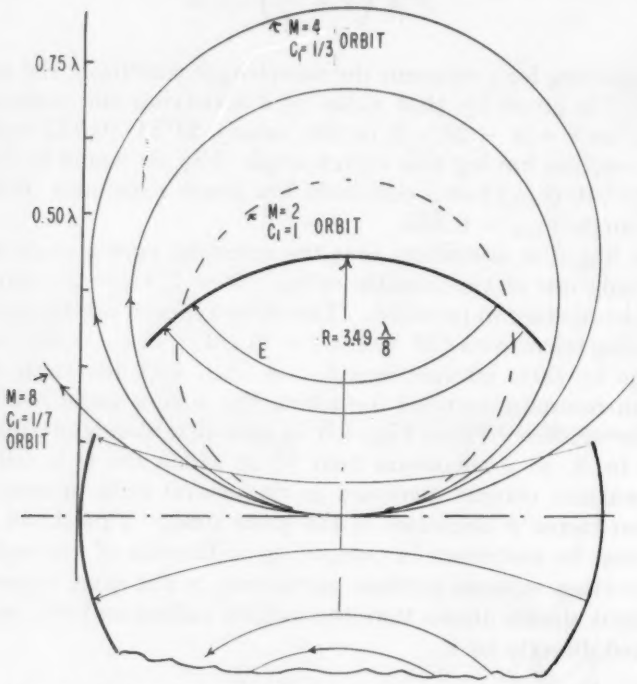

FIG. 4. Spherical resonator cross section and electron first orbits.

disadvantage is the long particle gap length along which the electric field intensity will be at its lowest value and least suitable for field emission extraction of electrons. The particle orbit however will follow along the electric lines for large radii orbits and this may be an advantage when the electrons are injected from an external source. The same remarks apply in the case of an ellipsoid of revolution.

II. RESONATORS MAINLY OF RECTANGULAR CROSS SECTION

A simple cylinder oscillating in the TM_{010} mode may be considered for use as a microtron resonator. The cylinder radius for resonance is (6)

$$b = \frac{2.405\lambda}{2\pi} = 0.3828\lambda = 3.0632\,\frac{\lambda}{8}. \tag{6}$$

The relationship of the cylinder to possible types of orbits is shown in Fig. 5(*a*). While the smallest orbit ($M = 1$, $C_1 = 2$) cannot thread a

simple cylinder, any of the others may be accommodated by a cylinder of restricted length l as determined by the points x, x' shown. The cylinder length is given by

$$l = (4br_m - 2b^2)^{\frac{1}{2}} = 0.2712(5.235k_1M - 1)^{\frac{1}{2}}\lambda_0. \tag{7}$$

Letting the utilization factor F again be the ratio of resonator cross section to orbital area (in this case some of the cross section is found outside the orbit circle), this ratio is given by

$$F = \frac{bl}{\pi r_m^2} = \frac{b(4br_m - 2b^2)^{\frac{1}{2}}}{\pi r_m^2}. \tag{8}$$

For the first possible threading orbit, this is about 0.57. In practice the cylinder would not be used open-ended but will be closed with plates having irises whose size (minimum radius) will be determined by the orbit to be used. This is given by

$$a = r_m - (b - r_m) = 2r_m - b = 1.345\lambda/8 = 0.168\lambda.$$

When a simple cylinder is fitted with ends containing circular irises the resonance radius of the cylinder is reduced in accordance with the relation (**7**)

$$b = \frac{\lambda}{2\pi}\left(2.405 - 0.982\,\frac{2J_1(Ka) - KaJ_0(Ka)}{2Y_1(Ka) - KaY_0(Ka)}\right), \tag{9}$$

where K is $2\pi/\lambda$ and J_0, J_1, Y_0, Y_1 are Bessel functions.

This type of resonator may be given a certain degree of re-entrance to shorten the acceleration gap and this in turn will be found to lead to still further reduction of resonant radius. Design curves (**8, 9**) are available for the dimensioning of the re-entrant rectangular toroidal resonators. Using these, two tentative cross sections were deduced which were square and therefore of high utilization factor. These are

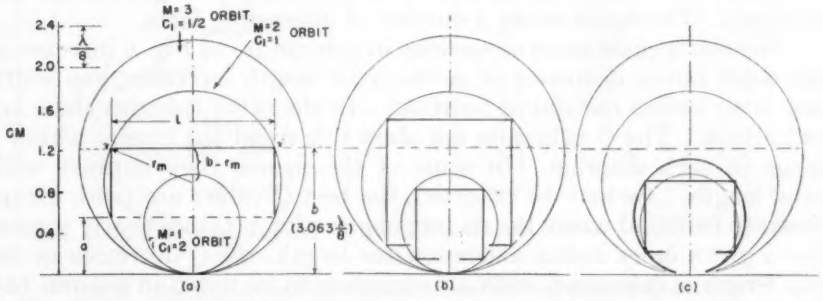

FIG. 5. Cylindrical-toroidal resonator cross sections in relation to electron first orbits.

shown in Fig. 5(*b*). The larger is doubtful since its diameter is greater than that for the resonant simple cylinder but the smaller is in substantial agreement with sections known to resonate and which are discussed further on.

Figure 5(*c*) shows two sections of practical interest. One of these—a rectangular section—is composed of two pill box and post (E-shaped) resonators placed face to face to create a resonator with a symmetrically placed gap. Each half is a section known to resonate by itself at the given wavelength (3.2 cm.). The composite section was found to resonate at nearly this same wavelength (3.24 cm.). Its cross section almost allows a fit into the smallest type of orbit, and one is tempted to say that with a rounding of the corners this might be accomplished. The other resonator—with a completely circular toroidal shape—shown in Fig. 5(*c*) was found however to have a maximum internal radius of $0.3704\,\lambda$, close to $0.3835\,\lambda$ for the simple cylinder. This suggests that there is a limitation on rounding of re-entrant forms and that the simple cylinder may be rounded without too much change in radius for resonance. In contrast, the deformation tending to produce a sphere and cone-shape resonator leads to a considerable reduction of maximum radius, which becomes $\lambda/4$ in the limit. It is interesting that this does not occur in the case of the circular toroid although it has a decidedly re-entrant section. For an orbit circle of the type $M = 2$, $C_1 = 1$ the circular toroidal section has a particularly good utilization factor (0.4525) which may be compared to the value 0.2025 for a sphere and cone section for the same orbit.

It is possible to find a large number of re-entrant rectangular sections which will fit into the smallest type of orbit circle. Figure 6 has been constructed from published data (9) for a large number of klystron resonator sections which have been designed and tested in part for resonance at $\lambda = 3.2$ cm. It shows the relation of some of these cross sections to the smallest types of orbit circles, and the values of Q and R_s obtained in such cases. Liberty was taken to change the gap from unsymmetrical to a symmetrical form which should not have too serious an effect since the total post height and gap length remain unchanged. The figure shows a number of interesting facts.

The shunt resistances of sections in column (*c*) of Fig. 6 increase as the outer radius decreases or as the axial length increases, gap width and inner radius remaining constant. In the other columns there are exceptions. The Q values do not show this trend but cluster within a range in each diagram. In some of the figures they improve with axial length. As may be expected, the best Q values are (with exceptions) to be found where the rectangular section becomes nearly square. For a given inner radius and resonator length, the Q decreases as the gap length is decreased, with an exception to be noted in column (*a*). For a given inner radius and axial length, both Q and R_s increase with

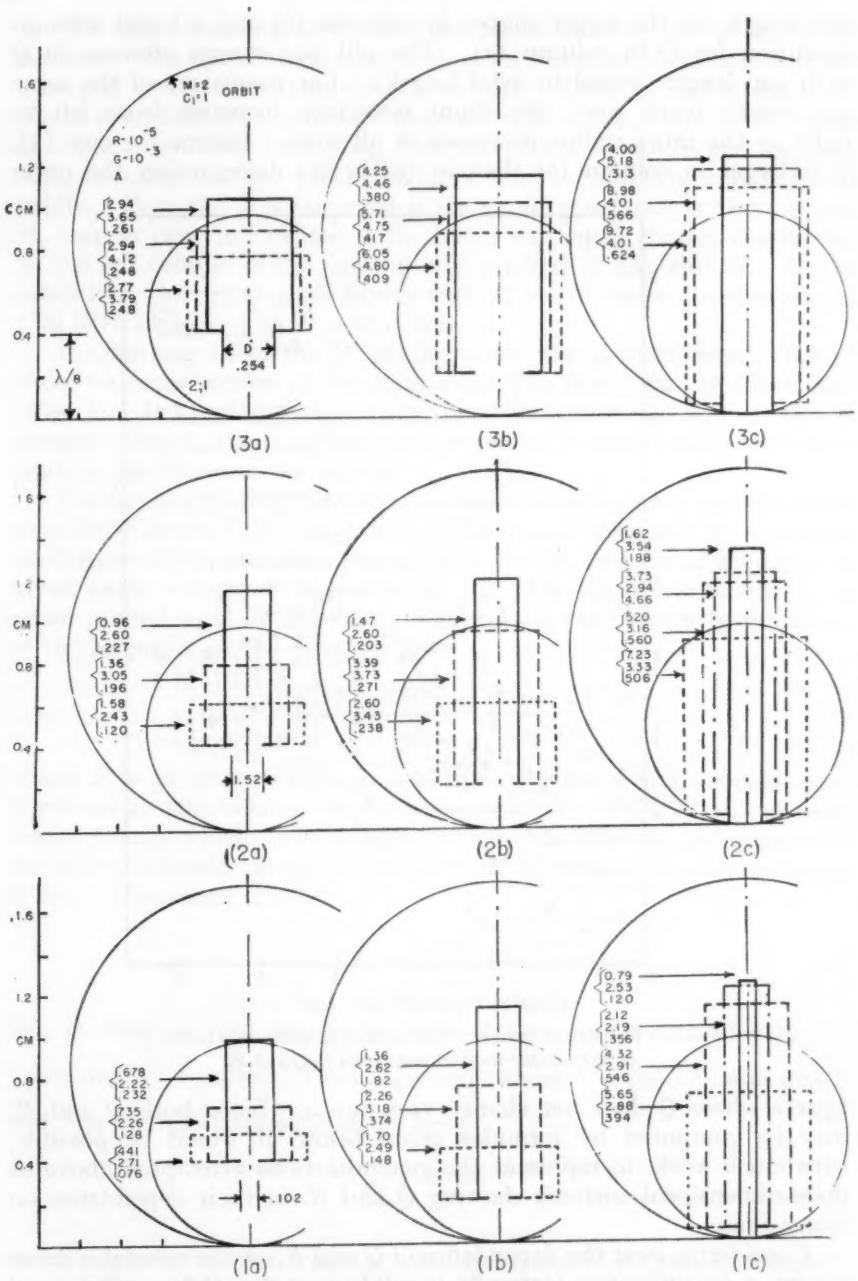

FIG. 6. Rectangular-toroidal resonator cross sections, electron first orbits, and electrical characteristics.

gap length for the larger shapes in columns (*b*) and (*c*) and with an exception for Q in column (*a*). The pill box shapes increase in Q with gap length (equal to axial length). For resonators of the same gap length (each row), the shunt resistance increases from left to right as the inner radius decreases in all rows. Except for row (1), Q is larger in column (*b*) than in (*a*) or (*c*) disregarding the outer

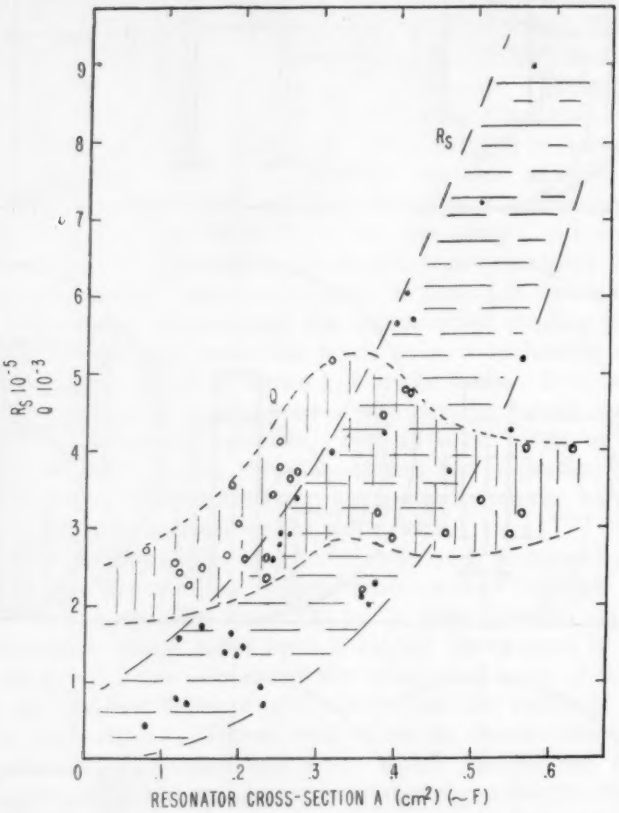

FIG. 7. Relation of cross sectional area A or utilization factor F, of rectangular-toroidal resonators to Q and R_s.

figures where Q does not change very much. Since both Q and R_s may be computed by formulas given below, it would be possible, with much work, to represent the generalizations attempted above as three-dimensional surfaces showing Q and R_s in their dependence on dimensions.

Considering next the dependence of Q and R_s on the resonator cross section A (or utilization factor F), it will be seen that Q does not depend very strongly on the cross section. Except for a tendency to be larger

for the larger sections, it is influenced much more by the shape of the section. The shunt resistance R_s shows a much more definite dependence and varies more than directly with A. Thus, in (1c) R_s increases about sevenfold for a threefold increase in A. The center of the figure is a transition zone from long thin sections to band-shaped sections. This contains sections which might be used on even the smallest first orbits. Here the Q is fair even if the shunt resistance is low. Q and R_s may or may not change with A and may even change oppositely. In the left column of the figure Q changes little if any with A. In the lower left, (1a), R_s changes slowly with A, in (2b) more directly, and in (3a) little change in Q, R, and A occurs.

By plotting all of the Q and R values, the general dependence of these on cross section A (without regard to form) can be illustrated (Fig. 7). It is evident that while the shunt resistance R_s increases in general with A, the Q values show a gentle increase augmented by a peak in the center of the region.

The factors relating the resonator dimensions to power and efficiency may be discussed at this point. The power required to maintain oscillation of the unloaded resonator is $V^2/2R_s$ and the efficiency at a given peak voltage V improves as R_s. The shunt resistance R_s is again related to Q by $R_s = QX_c$ where X_c is the capacitive reactance of the resonator. The power is then

$$P_r = \frac{\omega C V^2}{Q_0} = \frac{\omega \eta E^2}{Q_0} = \frac{\text{const. } \omega V^2 \text{ vol.}}{Q_0}, \tag{10}$$

where E is an average electric field intensity and η is a constant proportional to the volume of the resonator (12). ($CV^2/2$ is the peak stored energy which, it is assumed, can be obtained by integration of the stored electric energy in an element of volume in the resonator E^2dv.) Then since $E \sim V$

$$R_s = \frac{\text{const. } Q_0}{\text{vol.}}. \tag{11}$$

But Q_0 itself is very nearly the ratio of the resonator volume to the "skin depth" volume. Then $Q_0 = \dfrac{\text{vol.}}{S\delta}$ where δ is the r.f. skin depth and S is the resonator surface. Then

$$R_s = \frac{\text{const.}}{S} \tag{12}$$

which might be inferred from the qualitative idea of resonator resistance varying inversely with amount of parallel conducting surface in the resonator.

The following equations have been derived (10) for computing the values of Q and R_s (neglecting the effect of gap length):

$$Q\delta/\lambda = \frac{2l}{\lambda}\frac{\ln b/a}{2\ln b/a + 1\left(\frac{1}{a}+\frac{1}{b}\right)} \tag{13}$$

$$R\delta/\lambda = 60\pi\left(\frac{2l}{\lambda}\right)^2\frac{(\ln b/a)^2}{2\ln b/a + 1\left(\frac{1}{a}+\frac{1}{b}\right)}. \tag{14}$$

The ratio of R to Q takes the simple form

$$R/Q = 60\pi\left(\frac{2l}{\lambda}\right)\ln b/a.$$

The data of Fig. 5 check this equation quite well. To get a further analytical insight into the effect of gap length, the following elementary analysis may be made. Regarding the resonator as a lumped constant circuit let us assume most of the resonator capacitance is concentrated in the gap region. Then,

$$C = \frac{\epsilon A_g}{d} = \frac{\epsilon\pi a^2}{d}, \tag{15}$$

and the capacitive reactance, X_c, may be shown as

$$X_c = \frac{d}{\epsilon\omega\pi a^2}. \tag{16}$$

Then

$$R_s \doteq Q\frac{d}{\epsilon\omega\pi a^2} = \frac{d}{\epsilon\omega\pi a^2}\cdot\frac{\text{vol.}}{\text{surf.}}. \tag{17}$$

Neglecting volume and surface corrections for gap, the volume-to-surface ratio can be expressed in simple form,

$$\frac{\text{vol.}}{\text{surf.}} = \frac{1}{2}\left(\frac{b}{b^2-a^2}+\frac{1}{l}\right)^{-1}.$$

There results an approximate expression giving R_s in its dependence on all dimensions:

$$R_s \doteq \frac{1}{2\epsilon\omega\pi}\cdot\frac{d}{a^2}\frac{1}{\left(\frac{b}{b^2-a^2}+\frac{1}{l}\right)}. \tag{18}$$

This relation, and a similar one derived from Eq. 14 showing the dependence of R_s on gap length, follow the data of Fig. 5 only approximately. A more involved relation is required to show the dependence precisely. It has been shown (10) that for a given gap length d and inner radius a, R_s will have a maximum value when the cross section is nearly square. Holding a and d constant, differentiation of (14) will show that R_s must have a minimax given by the transcendental equation

$$\ln R = \frac{-a(1+R)}{1+\frac{aR}{2}}, \tag{19}$$

in which

$$R = a/b.$$

Although the rectangular-toroidal resonators have a simple and practical form, the complete theory of such resonators involving as it does impedance of a succession of changing radial wave guides is by no means simple. A recent approach combining such theory with electrolytic tank studies has been made (11).

III. CONFOCAL ELLIPSOIDAL-HYPERBOLOIDAL RESONATORS

Resonators of this type have in general much better values of Q and R_s than those of the other types discussed above. It is of interest, therefore, to determine analytically the confocal configuration of largest cross section fitting into a given minimum orbit area, which will resonate at the wavelength stipulated. The conditions are illustrated in Fig. 9. To begin with, certain parameters are specified. These are the wavelength λ, the resonant gap length d, and the aperture of the resonator throat measured by its radius h to the point of minimum gap length. The wavelength λ immediately gives a series of possible orbital radii one of which is selected as a related parameter r_m.

The largest resonator cross section that can fit into a given orbit is that for which the coordinates of intersection of the plane sections of the ellipsoidal and hyperboloidal surfaces of revolution (dotted lines) (Fig. 8) lie on the orbit circle. The gap edge coordinates (d, h) must lie within the circle. The hyperbola and the orbit circle define a point (d', h') which is the limit to which the hyperbolic sections may extend and which may be computed when the parameters of the hyperbola are determined.

The equations of the sections (through the axis of revolution) of the hyperboloidal and ellipsoidal surfaces are given by

$$\frac{x^2}{a'^2} - \frac{y^2}{b'^2} = 1 \quad \text{and} \quad \frac{x^2}{a''^2} + \frac{y^2}{b''^2} = 1, \quad \text{respectively.}$$

The equation of the orbit circle with center at $(0, r_m)$ is $x^2 + y^2 = 2r_m y$. Designating the intersection coordinates of the hyperbola and the ellipse as (X, Y), these must satisfy the simultaneous equations:

$$\left.\begin{aligned} \frac{X^2}{a'^2} - \frac{Y^2}{b'^2} &= 1 \qquad (20) \\ \frac{X}{a''^2} + \frac{Y^2}{b''^2} &= 1 \qquad (21) \\ X^2 + Y^2 &= 2r_m Y. \qquad (22) \end{aligned}\right\}$$

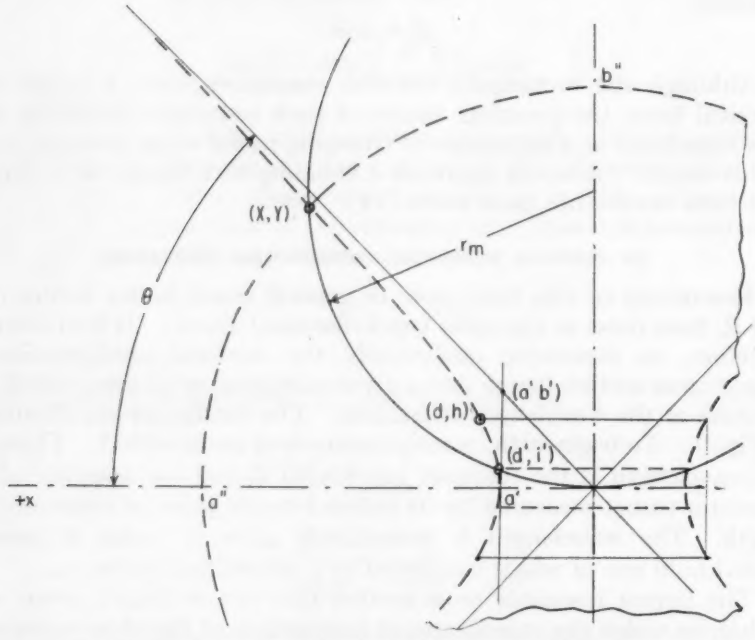

FIG. 8. Parameters of confocal-ellipsoidal-hyperboloidal resonators as related to electron first orbit.

The hyperbola and ellipse being confocal gives the condition

$$a'^2 + b'^2 = a''^2 - b''^2. \qquad (23)$$

On these coefficients is a further condition involving the wavelength for resonance

$$b'' = f(\lambda, a', b'). \qquad (24)$$

Finally, since the point (d, h) specifying the throat aperture at

minimum gap length must also lie on the hyperbola, there is an additional equation

$$\frac{d^2}{a'^2} - \frac{h^2}{b'^2} = 1. \tag{25}$$

Equations 20, 21, and 22 can be combined by eliminating X and Y into a single equation relating a'', b'', a', b', and r_m (or λ). This equation together with Eqs. 23, 24, and 25 gives a set of four equations relating the four coefficients a'', b'', a', b' from which it is possible to compute these in terms of r_m (λ), d, and h, the quantities of primary interest.

To begin with, Eqs. 20 and 21 may be solved for X^2 and Y^2.

Substituting into Eq. 22 and simplifying then gives

$$\frac{(a''a')^2}{b''b'} + b''b' = 2r_m(a'^2 + b'^2)^{\frac{1}{2}}. \tag{26}$$

Using the definition for the eccentricity of the hyperbola,

$$e_h = \frac{(a'^2 + b'^2)^{\frac{1}{2}}}{a'} = \sec\theta, \tag{27}$$

and the confocal condition 23 rewritten to read

$$a''^2 = b''^2 + a'^2 + b'^2 = b'' + a'^2 e_h^2, \tag{28}$$

one obtains from Eq. 26

$$b'' = \frac{r_m}{e_h}\left(\frac{b'}{a'}\right) \pm \left\{\left(\frac{r_m}{e_h}\frac{b'}{a'}\right) - a'^2\right\}^{\frac{1}{2}}, \tag{29}$$

which again by Eq. 27 may be written in the alternate forms

$$b'' = r_m\left(\frac{e_h^2 - 1}{e_h^2}\right) \pm \left\{r_m^2\left(\frac{e_h^2 - 1}{e_h}\right) - \left(d^2 - \frac{h^2}{e_h^2 - 1}\right)\right\}^{\frac{1}{2}}, \tag{30}$$

$$b'' = r_m \sin\theta \pm \{r_m^2 \sin^2\theta - (d^2 - h^2\cot^2\theta)\}^{\frac{1}{2}}, \tag{31}$$

where a' is given its value determined by Eqs. 25 and 27. From Eq. 31 it is seen that, given r_m (or λ) and the gap parameters d and h, b'' becomes known as soon as θ is determined. Now, since Eq. 24 can be expressed in such a form that it involves only λ and θ, b'' may be eliminated between Eqs. 24 and 31 to determine θ.

In Fig. 9 (from Hansen and Richtmeyer (2)), Eq. 24 is plotted in the form

$$\lambda/x_0 = f(\sigma_0), \tag{32}$$

where $x_0 \equiv b''$ and σ_0 is the confocal design parameter which is defined as

$$\sigma_0 = \frac{2x_0}{a} = \frac{b''}{(a''^2 - b''^2)^{\frac{1}{2}}} = \frac{b''}{(a'^2 + b'^2)^{\frac{1}{2}}} = \frac{b''}{a'e_h}. \tag{33}$$

Inspection of $f(\sigma_0)$ (which cannot be expressed analytically over its

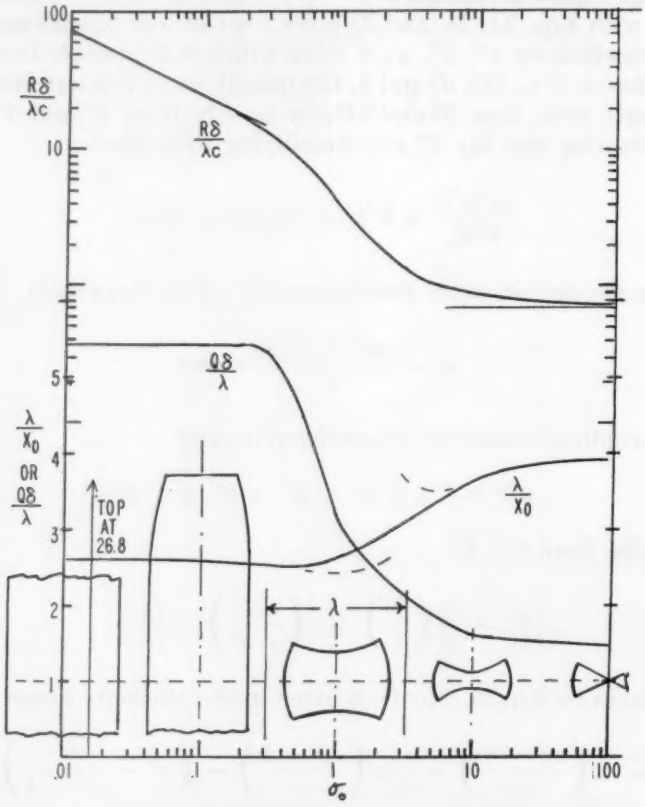

FIG. 9. Curves for Q, R, and λ/X_0 of confocal ellipsoidal-hyperboloidal resonators (Hansen and Richtmeyer).

entire range and which was determined mainly by numerical integration) shows that

$$f(\sigma_0)\begin{cases} = 2.5 \quad (\sigma_0 < 0.5) & (i') \\ = 2.4 - 3.5\ (0.5 < \sigma_0 < 10) & (i'') \\ = 3.5 - 3.8\ (10 < \sigma_0 < 100) & (i''') \\ \to \infty \quad \text{as} \quad \sigma_0 \to \infty & (i''''). \end{cases} \tag{34}$$

Since σ_0 is the ratio of the resonator diameter to the distance between

focal points, it is a measure of the diameter-to-length ratio of the resonator. Then only the range covered by (i'') is of much interest for design of microtron resonators. Over this range the curve for $f(\sigma_0)$ may be represented by the approximate equation

$$f(\sigma_0) \equiv \frac{\lambda}{x_0} \doteq 3.50 - \frac{0.90}{\sigma_0}, \tag{35}$$

which solved for σ_0 (using Eq. 33) gives

$$\sigma_0 = \frac{0.90}{3.50 - \lambda/b''} = \frac{k}{l - \lambda/b''} = \frac{b''}{a'e_h}, \tag{36}$$

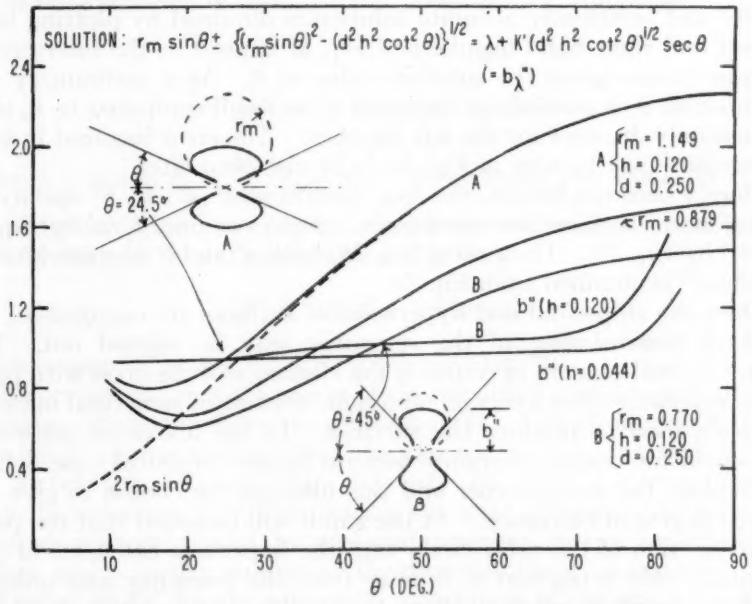

FIG. 10. Solution of design equations for confocal ellipsoidal-hyperboloidal resonators.

where k and l are constants which may be corrected empirically. This now allows the writing of an explicit equation in form of Eq. 24

$$b'' = \frac{1}{l}\{\lambda + ka'e_h\} = \lambda' + k'a'e_h, \tag{37}$$

using the abbreviations

$$\lambda' = \lambda/l \quad \text{and} \quad k' = k/l.$$

Equation 37 gives b'' in terms of θ and λ since a' may be expressed as in Eq. 30 in terms of the gap parameters d and h. Thus,

$$b'' = \lambda'_i + k'(d^2 - h^2 \cot^2 \theta)^{\frac{1}{2}} \sec \theta. \tag{38}$$

Equations 38 and 31 now give a single equation in which θ is the only unknown. (The pair (37) and (30) likewise give one which may be solved for $e_h = \sec \theta$).

$$r_m \sin \theta \pm \{r_m^2 \sin^2 \theta - (d^2 - h^2 \cot^2 \theta)\}^{\frac{1}{2}} = \lambda - k'(d^2 - h^2 \cot^2 \theta)^{\frac{1}{2}} \sec \theta. \tag{39}$$

This equation is cubic in $\sec^2 \theta$, (e^2) and may be solved by the standard methods for the solution of cubic equations. The explicit form is rather cumbersome and will not be given here. A much simpler and sufficiently accurate solution is obtained by plotting both the left and right hand members of Eq. 39 against θ; the intersection of these curves gives the solution value of θ. As a preliminary approximation it is possible to disregard a' as small compared to $r_m \sin \theta$ and use only $2r_m \sin \theta$ for the left member. The error incurred in such a procedure may be seen in Fig. 10 to be discussed later.

Once θ becomes known, the four quantities a', a'', b', b'' specifying the resonator surfaces become known. θ gives at once b'/a' by Eq. 27 and b'' by Eq. 37. Then using Eq. 25, both a' and b' become known. Finally a'' is obtained from Eq. 23.

Once the ellipsoidal and hyperboloidal surfaces are established, the practical dimensioning of the resonator may be carried out. The matter of final concern of course is the clearance of the orbit with parts of the resonator after a certain minimum amount of structural material has been used to produce the surfaces. In the above no allowance was made for corner clearance because in any practical case a fillet will replace the sharp corner and this fillet can be chosen to give the desired degree of clearance. At the gap it will be found that the point of intersection of the orbit circle with the hyperbola extended (d', h') is usually only a fraction of h away from the resonator axis unless h has been specified quite small to begin with. In practice, h can be specified with the desired clearance of the orbit circle at the desired aperture.

The above outlined design theory may now be compared to some practical results observed in the making of some resonators for X-band microtron operation.

The first item to be considered is the wavelength relation Eq. 24 or Eq. 37. Using the constants obtained from the approximate equation for the Hansen-Richtmeyer curve (Eq. 35), then, for a wavelength of 3.203 cm. (9375 Mc.)

$$b'' = 0.917 + 0.257\, a' e_h. \tag{40}$$

For the resonators mentioned, a curve was drawn which represented the average values of b'' for a series of resonators having a range of different gap lengths ($2d$). This curve taken at two arbitrary values of d equal to 0.200 and 0.300 gave values of b'' of 0.972 and 1.004, respectively. To compute from this curve a set of constants for λ' and k' to compare with those of Eq. 17, Eq. 38 was rewritten expanding the square root value of a' by the binomial theorem giving

$$b'' = \lambda' + k'd \sec\theta - \frac{k'h^2}{2d} \csc\theta \cot\theta + \cdots. \tag{41}$$

The terms in the expansion decrease rapidly as may be seen by substitution of data, and for determination of the coefficients, only three terms were retained to form the two observational equations

$$b_1'' = c_1 + c_2x_1 - c_3/x_1 \tag{42}$$

$$b_2'' = c_1 + c_2x_2 - c_3/x_2, \tag{43}$$

where $x \equiv d$ and $c_3 = \frac{h^2}{2} \cdot c_2 = kc_2$. From these, the values of c_1 and c_2 are deduced giving the closest adjustment of the constants in Eq. 37 for b'', which becomes from the available data

$$b'' = 0.944 + 0.245\, a'e_k \tag{44}$$

which is seen to be in good agreement with Eq. 40.

Before passing to a discussion of the next item, the determination of resonator parameters from the solution curves, a short discussion of the wavelength change that accompanies gap length change as implied from the wavelength relation (Eq. 24) may be made. Furthermore it might be remarked that this relation has some limitations since it was deduced without regard to any end opening in the hyperboloidal surface and is further subject to the question about an assumed value of θ equal to 45° for the numerical integration of the wave equation. Regarding the former it is known that these resonators are not too sensitive to end openings and for the latter it may be assumed for the present that the results expressed in the curve of Fig. 9 may be valid for a range to either side of $\theta = 45°$.

Writing Eq. 37 to make λ' explicit,

$$\lambda' = b'' - k'a'e_k. \tag{37}$$

This equation correctly predicts, qualitatively at least, that λ decreases as the gap length ($2d$) increases (when b'' is maintained fixed). In this case the wavelength changes linearly with $a' \sim d$ while the frequency

will change hyperbolically. By Slater's rule (13),

$$\frac{df}{f} = \frac{dv}{v}, \tag{45}$$

the frequency dependence should be linear with d if it is assumed that the volume change dv is proportional to the gap length change. A

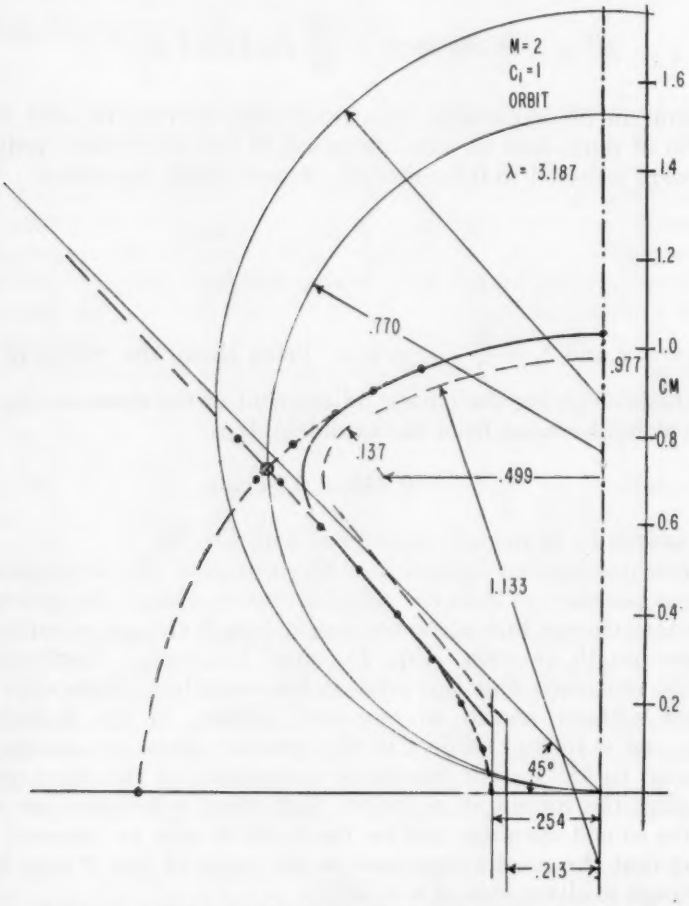

FIG. 11. Design of an X-band confocal ellipsoidal-hyperboloidal microtron resonator.

similar result may be obtained if the resonator is considered to be a lumped constant circuit for which

$$\lambda = k(LC)^{\frac{1}{2}} \qquad (k = 4\pi^2 c^2). \tag{46}$$

This may be interpreted so that L is determined by the flux-linking

geometry of the resonator and C is composed of the variable gap capacitance

$$C_0, \text{ i.e., } C = C_0 + \epsilon A/l_g.$$

Then,

$$\lambda = k(LC_0)^{\frac{1}{2}}\left(1 + \frac{\epsilon A}{2C_0 l_g} + \cdots\right) = \lambda_0 + \tfrac{1}{2}Z_0\frac{\epsilon A}{l_g} + \cdots \quad (47)$$

which may be compared again to Eq. 37:

$$\lambda' = b'' - \text{const.} \cdot l_g.$$

Over a small range of d, approximate linearity may be obtained regardless of the form of the expression. In the resonators mentioned above, both linear and hyperbolic dependence of frequency on gap length was observed and more data are required to reveal the reasons for the diverse behavior.

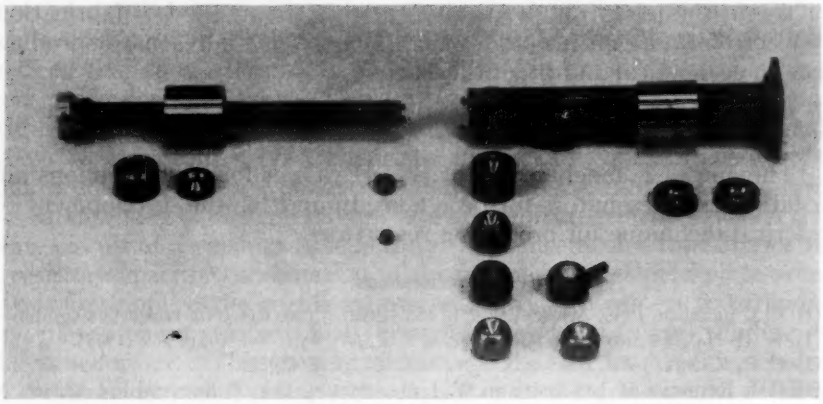

FIG. 12. X- and K-band microtron resonators in several stages of fabrication.

The resonant frequency of the resonator depends much more critically on gap length ($2d$) than on equatorial radius b''. This may be illustrated by some experience in a first design of a confocal resonator as shown in Fig. 11. Here a conservative orbit radius less than that of a ($M = 2$, $C_1 = 1$) type of orbit was chosen for design using the data of Fig. 9. This gave the profile shown in heavy line. Since the resonator with this contour did not resonate, it was wavelength-scaled to the contour shown in dotted line, but this reduced section required an even larger reduction of gap length (20 per cent) to resonate. Fortunately the resulting resonator of dimensions given in the figure has proved to be a very good resonator for X-band microtrons. Later studies showed that the larger radius section which was initially designed also operated well if the gap were enlarged slightly.

By using Eq. 44 with improved constants, one should be able to design resonators oscillating close to required frequency by the method given above. A study of several experimental resonators similar to that shown in Fig. 11 but having decidedly different radii and gap lengths, have parameter behavior to be expected from the theory above. Although allowance can be made in design for the resonance frequency change produced by cutting the coupling iris (tending to reduce resonant frequency), it is an easy matter to change the gap sufficiently to correct the frequency as the iris size is increased to its "matched" value. It may be noted here also that in scaling X-band confocal resonators to K-band size, the final diameters will be found to be about 80 per cent of that expected by simple wavelength scaling. This indicates a form-capacity factor which is not present in scaling of simple cylinders, these having been found to scale nearly exactly with wavelength.

Figure 12 shows several X- and K-band microtron resonators in various stages of completion and as mounted in a waveguide fixture for use in the microtron. Also indicated is the method of fabrication by electroforming on fusible forms. This has made resonator production an economical and practical matter.

Acknowledgment

The author is indebted to Mr. W. T. Mayes for his continuous aid in fabricating resonators for design study and for the development of practical technique for producing resonators.

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(10) See Ref. 8, p. 229.
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NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

SUBHARMONIC CRYSTAL OSCILLATOR

A subharmonic crystal oscillator circuit recently constructed at the National Bureau of Standards combines simplicity with versatility. The circuit requires only a single triode tube in a blocking oscillator circuit, coupled to a quartz crystal. Each output pulse of the oscillator "shock excites" the crystal, and the voltage generated by the crystal as it continues to vibrate or "ring" synchronizes the oscillator at a submultiple of the crystal frequency. With some crystals the circuit has been operated successfully at division ratios as high as 10,000 to 1, producing harmonic-rich output at 100 cycles per second controlled by a 1000 kilocycles-per-second crystal. The present circuit was a chance discovery of Dr. M. C. Thompson, Jr. of the NBS Sound Section, who, while working on a project sponsored by the Office of Naval Research, noticed that some equipment was oscillating in an unexpected fashion and proceeded to analyze and take advantage of the phenomenon. Although a search shows that a patent for a similar circuit was granted to W. A. Marrison in 1933, electronic engineers have apparently been almost entirely unaware of this signal-generating technique.

An ordinary blocking oscillator is a simple arrangement in which the plate circuit of a vacuum tube is coupled by means of a transformer to a resistor-capacitor combination in the grid circuit. When plate voltage is first applied the grid is at zero potential with respect to cathode, and plate current starts to flow through the primary (plate) winding of the transformer. This current quickly produces a large voltage pulse in the secondary that charges the capacitor in the grid circuit, driving the grid voltage far beyond the plate-current cut-off value. With the plate current thus cut off almost as soon as it has started, the grid capacitor discharges through the grid resistor until the grid voltage has recovered sufficiently to again permit a plate-current pulse to flow. The circuit keeps oscillating in this fashion, at a frequency determined largely by the time constant (product of resistance and capacitance) of the grid circuit. Blocking oscillators can be readily synchronized at submultiples of stable signals inserted in their grid circuits; as the grid recovers after being blocked, the tube will fire at or near a positive peak of the synchronizing voltage.

In the crystal-controlled blocking oscillator being used at NBS, the necessary synchronizing signal is obtained simply by coupling a quartz crystal to an ordinary blocking oscillator, by means of a third transformer winding. Alternatively, the crystal can be connected across

*Communicated by the Director.

either the grid or plate winding of the transformer, or connected directly between grid and plate. Coupling by means of a third transformer winding seems preferable, however, since it avoids d-c voltage on the crystal and permits grounding the rotor of a trimmer condenser placed across the crystal.

Division ratios as high as 10,000 to 1 have been obtained only with a few crystals. Such extreme ratios would probably seldom be of practical value; a small change in circuit constants might cause the fundamental frequency to change from 1/10,000 to 1/10,001 of the crystal frequency, for instance, and such a small change in frequency could easily go undetected with ordinary equipment. Division ratios of several hundred are readily obtained, however, and can be maintained with high stability if supply voltages are held reasonably constant. Crystal-controlled signals can thus easily be generated at frequencies much lower than those of generally available crystals. The wide range of possible division ratios means that a desired fundamental frequency can be obtained from any of a large number of crystal frequencies. Conversely, a single crystal can be used to give crystal-controlled output at any of a large number of fundamental frequencies. The upper limit of blocking-oscillator fundamental frequency is determined by the characteristics of the pulse transformer; this limit appears to be above 200 kilocycles with a typical transformer.

NOTE: For a more complete description of this device, see "Subharmonic Crystal Oscillators," by Moody O. Thompson, Jr., Carroll E. Tschiegg, and Martin Greenspan, *Review of Scientific Instruments*, Vol. 25, p. 8 (1954).

MEASUREMENT OF CARBON 14 IN SOLUTION

A rapid, precise method for determination of carbon 14 in C^{14}-labeled substances has been developed by A. Schwebel, H. S. Isbell, and J. D. Moyer of the National Bureau of Standards. In this method the labeled material is first dissolved in a suitable solvent and then placed in a modified proportional counter which measures the radioactivity of the material. By keeping the specimen in solution, many of the problems inherent in the use of solid specimens—deposition of films, combustion, or plating of samples—are avoided. The procedure also permits the application of volumetric techniques and is particularly useful for the assay of highly active materials.

The use of carbon 14 as a radioactive tracer has become increasingly widespread since its discovery in 1940. Thus, to meet the needs of medical and biological research, the Bureau has prepared over 40 sugars and sugar derivatives having carbon-14 atoms located in specific positions within the molecule. These position-labeled compounds are used as tracers in a variety of complicated animal and plant metabolism studies. With the relatively large-scale availability of carbon 14 as a

tool for science and industry, it has become important to develop adequate instrumentation for measuring its beta radiations.

Relatively little instrumentation work has been done on measuring C^{14}-labeled compounds in solution with windowless proportional counters. Direct measurement of the radioactivity of solid sources is complicated by variations in self-absorption back-scattering, and forescattering, and (in counting on plastic backings) by the presence of static charges that distort the field. These variations do not occur with solutions, which are quite reproducible and have little tendency to hold static charges. Other complications arise, however, and it is not possible to obtain satisfactory assays with most solvents.

A satisfactory solvent for counting C^{14}-labeled materials in solution by means of a windowless proportional counter must meet several requirements: (1) it must be an adequate solvent for the material to be analyzed; (2) its vapor pressure must be low to avoid a change in the concentration of the solvent with time; (3) its vapors should not form a conducting path across the high-voltage-wire insulation in the counter; (4) it must have little or no tendency to creep over the edge of a container.

Numerous liquids were investigated at the Bureau in an effort to find a suitable solvent. Of those studied, ninety-percent phosphoric acid was found fairly satisfactory while purified formamide, dimethyl formamide, and ethylene glycol gave excellent results.

The solution to be assayed can be prepared by any convenient method. Readily soluble materials are dissolved directly in the counting liquid. Samples received in aqueous solution are handled by first taking a definite volume (up to 0.1 ml) of the sample in a mixing pipette and then adjusting the volume to 1 ml with the solvent. The separation of insoluble precipitates or of a second liquid phase must of course be avoided. To minimize errors that might arise from adsorption of the radioactive material on the container or from concentration of the sample on the surface of the counting liquid, highly active materials are diluted with a suitable quantity of the corresponding nonradioactive material when the solution is prepared for counting.

To adapt commercially available proportional counters for the assay of liquid samples, it is necessary to fit them with a suitable container for the liquid. A stainless-steel cell holding a maximum of 1.1 ml of solution was used in this study. To prevent contamination of the counter, the cell is handled by means of a bolt that fits a tapped hole and serves as a removable handle. The container is water-cooled to prevent decomposition of the formamide and to minimize evaporation of volatile constituents from the solution.

The proportional counter used is designed so that a continuous stream of gas flows at atmospheric pressure through the counting chamber which contains the material to be analyzed. After the solu-

tion is placed in the counter, the system is thoroughly flushed with the counting gas and the run is made. Radiation from the material under analysis produces ionization in the chamber; this leads to a momentary discharge across the high-voltage field maintained between the wall of the chamber and a wire anode. The change in potential caused by the discharge is converted into a current pulse that activates a recording mechanism by means of a vacuum-tube amplifier. For maximum precision, background determinations are made before and after each measurement.

To convert the observed counts per second (c.p.s.) to the absolute disintegration rate (d.p.s.) or to microcuries of C^{14} per milliliter of solution, it is necessary to standardize the procedure by counting a solution containing a C^{14}-labeled substance of known radioactivity under conditions comparable to those used in the analysis. In the present study several such substances were used for standardization.

To prepare a solution of a material for use in standardizing the counter, the radioactivity of the material is determined by oxidizing it, transferring the carbon dioxide to an ionization chamber, and using this chamber with a vibrating-reed electrometer. The electrometer rate of drift obtained with this unknown is then compared to the drift rate obtained with the carbon dioxide in a sample of the NBS C^{14} Beta Ray Standard. A known concentration of the standardized material in formamide or other solvent is then used to determine the efficiency of the counter.

Any comparison of counting rates must take into consideration the density of the solution used because the absorption of beta radiation is proportional to the density of the absorbing medium. For this reason, the counting efficiency (c.p.s./d.p.s.) in a given counter should be inversely proportional to the density of the solution counted.

A detailed study of data for D-mannitol-1-C^{14} dissolved in a variety of solvents and for a number of C^{14}-labeled materials dissolved in the same solvent shows that the product of the counting efficiency and the density is substantially a constant regardless of the substance counted or the solvent. This gives rise to a constant calibration factor that can be used for converting the count of an unknown sample to microcuries of C^{14} per ml. Thus for all carbon 14 labeled materials the absolute disintegration rate in microcuries is given by the product of the observed counting rate, the density of the solution, and the calibration factor.

The densities of solutions containing small quantities of a solute in a particular solvent do not vary widely. Hence, it is not necessary to determine the densities of all solutions for routine measurements. Frequently no substantial error is introduced by using the density of the solvent as the density of the solution.

To obtain an indication of the precision of the solution counting

technique, measurements were made at the Bureau on a C^{14}-labeled sugar in formamide and in ethylene glycol using three proportional counters differing slightly in counting efficiency. A statistical treatment of the disintegration rate of a radioactive substance would lead one to expect a standard deviation in these measurements of ± 309 for 95,000 counts. The actual standard deviations obtained for the experimental data are only slightly higher than this value, indicating that C^{14}-labeled compounds can be reproducibly counted in solutions of either formamide or ethylene glycol.

NOTE: For further technical details, see Determination of Carbon 14 in Solutions of C^{14}-Labeled Materials by Means of a Proportional Counter," by A. Schwebel, H. S. Isbell and J. D. Moyer, *Journal of Research of the National Bureau of Standards*, Vol. 53, No. 4 (RP 2537).

THE FRANKLIN INSTITUTE

MINUTES OF STATED MEETING

December 15, 1954

The Stated Monthly Meeting of The Franklin Institute was held on December 15, 1954, in the Lecture Hall. S. Wyman Rolph, President, called the meeting to order at 8:20 P. M. Approximately 410 members and guests were in attendance.

The President stated that the Minutes of the October Stated Meeting were printed in the November JOURNAL and asked if there were any corrections, additions or changes. None being offered, they were approved as submitted. Minutes of the November Stated Meeting will be printed in the December JOURNAL and will be submitted for approval at the next Stated Meeting.

The Secretary reported that the following nominations for election to the Board of Managers had been made in conformity with Article IV, Section 5, of the By-Laws:

Henry B. Bryans	W. H. Fulweiler
Francis J. Chesterman	Gaylord P. Harnwell
James Creese	Harold LeDuc
Rupen Eksergian	Emery W. Loomis

The President then called for nominations from the floor. There being none, he declared the nominations closed. George S. Crampton, Joseph S. Hepburn, and Howard Stoertz were appointed Tellers.

The Secretary reported that elections to membership, recorded since October 31st, resulted in a net gain in the following classes of membership:

Active	8
Associate	1

and a total membership, including individuals with Library privileges under Company membership, of 6,835 as of November 30, 1954.

He read the names of the 22 members who had completed twenty-five consecutive years of membership in the Institute during 1954 and who have consequently received Silver Cards of Membership. (These are listed under the Membership Section of the JOURNAL.)

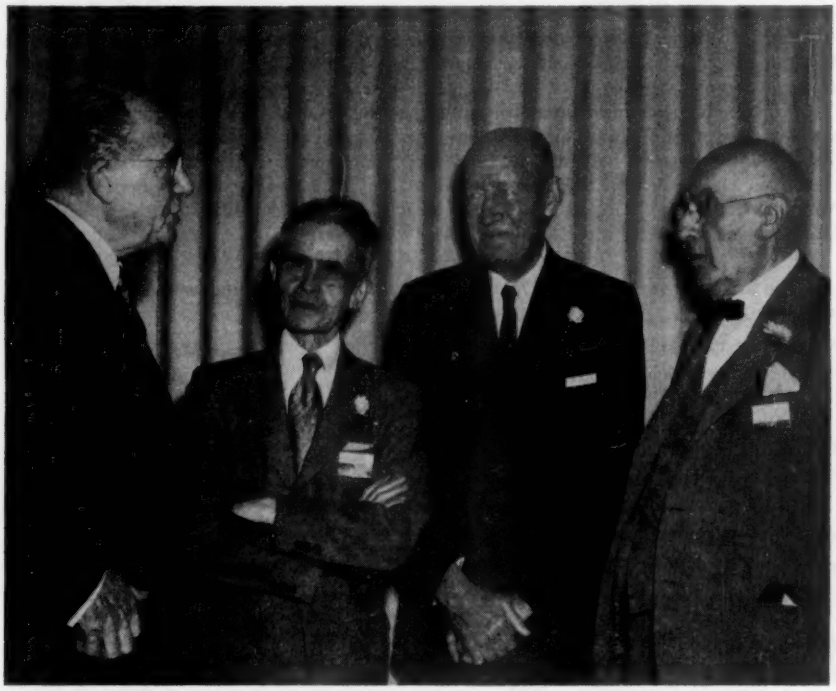
The President then introduced the speaker of the evening, Dr. Hubert N. Alyea, Professor of Chemistry at Princeton University, who discussed in a popular manner "Lucky Accidents in Chemistry." Dr. Alyea's delightfully humorous lecture was profusely illustrated with eye-catching and ear-deafening illustrations, and was enthusiastically received by the audience. The meeting adjourned at 10:20 with a rising vote of thanks to Dr. Alyea.

HENRY B. ALLEN
Secretary

MEMBERSHIP

NEW GOLD CARD MEMBERS HONORED

At the Stated Meeting on November 17, The Franklin Institute honored Frank S. Busser and C. Mahlon Kline, both of Philadelphia, for fifty years of continuous membership in The Franklin Institute. Morton Gibbons-Neff, Chairman of the Membership Committee, spoke briefly of the achievements of the two men before presenting them to the President, S. Wyman Rolph. In honor of their fiftieth anniversary as members, Mr. Rolph presented gold keys and gold membership cards to Messrs. Busser and Kline. James M. Caird, of Troy, New York, a member since 1901, was on hand to congratulate the two new Gold Card Members.



S. Wyman Rolph, President of the Institute, congratulates Frank S. Busser and C. Mahlon Kline (left to right), on their fifty years of continuous membership, as James M. Caird, past Gold Card Member, looks on.

The following brief biographies of the new Gold Card Members will serve to bring some of their accomplishments to the attention of the members who were not able to attend the meeting.

FRANK S. BUSSER

Born in York, Pennsylvania, Frank S. Busser was graduated from York High School. Following graduation, he became a shorthand writer in the law offices of the late George Harding. Mr. Busser later prepared and prosecuted applications for patents and thus received the stimulus to study law. He was graduated *cum laude* in 1897 from the University of Pennsylvania Law School and was admitted to the local bar in the same year.

While continuing to practice as a patent solicitor, he devoted a great deal of his time to patent litigation, finally forming the firm of Busser, Smith and Harding, in which he is still

active. During Mr. Busser's professional life he has successfully handled litigated cases for many large corporations. He is currently General Patent Counsel for the Sun Oil Company.

Mr. Busser says he found in The Franklin Institute a well of information in technical arts, for use in the preparation of patent actions. Here he obtained, free of charge, a service of great value and (rather tardily he now thinks) concluded that becoming a member of the Institute, by the payment of a nominal annual fee, was obligatory.

C. MAHLON KLINE

C. Mahlon Kline, Chairman of the Board of Smith, Kline & French Laboratories, has been associated with the Philadelphia pharmaceutical firm since the turn of the century. Starting as a part-time helper in the laboratory and manufacturing plant of the company which his father, the late Mahlon N. Kline, helped to bring into prominence as a wholesale drughouse, Mr. Kline eventually served as analytical chemist, plant manager, Vice President and President. Now Chairman of the Board, Mr. Kline has devoted the major portion of his life to advancing medical science and the pharmaceutical industry.

Born in 1880 in Philadelphia, he was educated at Penn Charter School and the Sheffield Scientific School of Yale University, graduating from the latter in 1901 with a degree in Chemistry.

Intensely interested in matters concerning the welfare of the whole drug industry, he has been a trustee of the Philadelphia College of Pharmacy and Science and Second Vice President since 1927, receiving an honorary degree of Doctor of Science from that institution in 1939. He served as President of the Drug Exchange from 1925 to 1926, and as President of the National Wholesale Druggists Association from 1928 to 1929. In 1951, the Philadelphia Drug Exchange awarded Mr. Kline its famous Proctor Medal.

The following are Gold Card Members, having belonged continuously for fifty years or more:

Alexander Sellers '84
William Henry Bower '85
Fred H. Colvin '88
G. H. Clamer '91
J. H. Granberry '95
Edward Woolman '95
Alan Wood, III '96
T. C. McBride '97
D. S. Jacobus '99
John J. McVey '99
E. A. Muller '99
C. C. Tutwiler '99
James M. Caird '01
Kern Dodge '02
John P. B. Sinkler '02
Charles H. Howson '03
Frank S. Busser '04
C. Mahlon Kline '04

The following are Silver Card Members, having belonged continuously for twenty-five years or more. The dates are years of election to membership.

1905
George R. Hall

1906
John L. Cox
Francis J. Stokes

1907
Darthela Clark
Frank Shaw Clark

1908
W. M. C. Kimber
John B. Rumbough

1909
Theobald F. Clark
Walton Clark, Jr.
J. B. Klumpp
James McGowan, Jr.
George Missimer, Jr.
T. Edward Ross

1910
Richard B. Brown
Joseph S. Hepburn
Joseph W. Lippincott
Horace P. Liversidge
J. D. Shattuck
J. M. Weiss

1911
Seth B. Capp
W. H. Fulweiler
Charles Penrose
Frederic Rosengarten

1912
James Barnes
Morris Llewellyn Cooke
Edwin Elliot
Walter Palmer
Julian S. Simsohn
Howard S. Worrell

1913
Edward Bartow
Sterling H. Bunnell
Irenee duPont
S. B. Eckert
Ralph E. Flanders
N. E. Funk
Lionel F. Levy
E. Mallinckrodt, Jr.
Frank M. Masters

Franklin P. McConnell
William Maul Measey
W. Chattin Wetherill
D. Robert Yarnall

1914

Russell L. Brinton
George S. Crampton
Ernest L. Huff
K. G. Mackenzie
George Wharton Pepper

1915

Thomas D. Cope
John C. Cornelius, Jr.
H. Jermain Creighton
Thomas W. Elkinton
Richard Howson
W. Wallace McKaig

1916

Henry B. Allen
James G. Detwiler
Zay Jeffries
Thorsten Y. Olsen
Frank H. Sauer
B. E. Shackelford
H. B. Spencer
Arthur Synnestvedt
Leo Wallerstein
Charles N. Weyl

1917

A. D. Chambers
Francis J. Chesterman
Walter S. Crowell
P. T. Dashiell
William J. Fitzmaurice, Jr.
Rolfe E. Glover, Jr.
Harold Goodwin, Jr.
Arthur W. Lowe
Frank S. MacGregor
Francis F. Milne, Jr.
C. H. Quinn
Sylvan D. Rolle
Robert L. Wood
Henry Woodhouse

1918

Charles H. Colvin
Charles H. Masland, 2nd
Walter O. Snelling

1919

Charles E. Brinley
Henry Colvin, 2nd
E. A. Eckhardt
George W. Furness
Frank H. Griffin
Hiram S. Lukens
H. Conrad Meyer
J. Howard Pew
Edmund G. Robinson
L. K. Sillcox
W. Leigh Smith
John Sealy Townsend

1920

Robert Cameron Colwell
E. D. Doyle
Howard W. Elkinton
Francis W. Hartzel
Chester Lichtenberg
P. S. Lyon
Haviland H. Platt
Carl D. Pratt

1921

Roland L. Andreau
Leonard T. Beale
J. Ed. Brewer
Arthur L. Day
Frederic Palmer, Jr.
Howard Stoertz
James Stokley
Haakon Styri
Edward R. Weidlein
S. Weinberg

1922

C. Douglas Galloway
Joseph F. Greene
C. E. K. Mees

1923

C. S. Chrisman
William Dubilier
Henry Clay Gibson
Howard S. Levy
William C. Melcher, Jr.
John F. Metten
Jessie A. Rodman
Edwin G. Sagebeer
Coleman Sellers, 3rd
H. Birchard Taylor
Francis B. Vogdes
Joseph J. Vogdes

1924

Peter Abrams
H. Carl Albrecht
Clement Starr Brinton
Karl K. Darrow
Lee Davidheiser
William G. Ellis
T. R. Harrison
Valentine Hiergesell
Karl F. Oerlein
Edward B. Patterson
Harold Pender
Nicholas G. Roosevelt
Alfred O. Tate
Walter C. Wagner
James Lloyd Weatherwax
Alexander Wilson, 3rd
William Zimmermann

1925

Jack G. Binswanger
William L. Brown, 3rd
Marion Eppley
John Graham Foley
J. V. Giesler
C. R. Kraus
J. Kenneth W. Macalpine
W. F. G. Swann

1926

Charles B. Bazzoni
Neils Bohr
O. E. Buckley
William Findlay Downs
Henry C. Evans
Edward L. Forstall
Lewis H. Hendrixson
Charles S. Leopold
Alfred L. Loomis
J. H. Manning
William Clarke Mason
Clement B. Newbold
O. M. Patton
Charles S. Redding
Dexter N. Shaw
Sydney L. Wright
Charles S. Wurts, Jr.

1927

T. K. Cleveland
Milton W. Deisley
William Dekrafft
Hiram B. Ely

Leslie Griscom
John W. Harsch
Alfred Iddles
John Van Gasken Postles
Philip Sporn
Charles A. Stanwick
Charles A. Young

1928

William R. Dohan
Walton Forstall, Jr.
C. W. Hansell
Walter A. MacNair
Ellice McDonald
Fred P. Nabenhauer
Joseph N. Pew, Jr.
William Rogers, Jr.
Frank N. Speller

1929

N. E. Bonn
M. M. Borden
Bernard Davis
Rupen Eksergian
Edward C. Haines
Isaac Harter
Malcolm Lloyd Hayward
Linn Helander
Randall Morgan, III
Harold F. Pitcairn
H. F. Porter
Edmund Rowland
Lawrence Saunders
A. Kelvin Smith
I. Melvin Stein
William Stericker
Harden Franklin Taylor
Jacques L. Vauclain
Albert G. Williams, Jr.
Arthur M. Wilson, Jr.
C. T. R. Wilson
Enos E. Witmer

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS

December 15, 1954

ACTIVE FAMILY

Martin H. Bury
Alfred A. Little
John C. Lyon
Edward B. Snyder
John Wayne Tiley
Paul B. Wendler

ACTIVE

Anthony J. Certa
John J. Deegan
William Douglass
Andrew A. Halacsy
Thomas Hudson, Jr.
Ethel W. Jacobsen
Samuel B. Jones
William C. Kay
Stuart R. Knapp
Joseph A. Lagore
Harold F. MacWilliams, Jr.
John J. McCartin
Henry Moser
John H. Murdoch, Jr.
Charles L. Petze, Jr.
William W. Pleasants
Morris W. Satinsky
Carl A. Schafer
Henry W. Seher
David Mason Shinefeld
Florence Ward Stiles
Louis D. Wilson

NON-RESIDENT

A. Ackerman
John W. McNabb

NECROLOGY

William Adam '27
Edwin M. Chance '11
Jacob Feldman '44
Enrico Fermi '47
M. Fulmer Hoffman '44
Almern C. Howard '52
Thomas I. Manly '48
Frank Mauran '36
R. H. Patch '46
Walter F. Rittman '15
Jeremiah J. Sullivan, Jr. '44
George B. Wood '44

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

HEROLD, E. W.: Semiconductors and the Transistor

FORSCHER, FREDERICK: Analysis of Continuity of One Phase in a Powder Mixture of Two Phases

MISHKIN, E.: Disturbances in the Induction Machine due to Broken Squirrel-Cage Rings

KU, Y. H.: Analysis of Nonlinear Systems with More Than One Degree of Freedom by Means of Space Trajectories

MALIC, DRAGOMIR: The Equation of Polytropic Process of Real Gases

MINORSKY, N.: On Asynchronous Action

PAI, S. I.: On the Stability of Parallel Flows with Respect to Periodic Disturbances

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, December 8, 1954.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 8, 1954.

PROFESSOR W. S. PARDOE in the Chair.

The following report was presented for final action:

No. 3258: Timing Belt.

This report recommended the award of an Edward Longstreth Medal to Richard Y. Case, of Philadelphia, Pennsylvania, "In consideration of his invention of a successful 'Timing' Belt, built upon a toothgrip design that makes positive engagement with axially cut grooved pulleys, thus producing a completely positive belt drive that does not depend upon frictional grip for the transmission of power and makes possible high precision timing between two or more shafts."

JOHN FRAZER,
Secretary to Committee

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A. M. until 5 P. M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; 2 P. M. until 10 P. M. on Wednesdays.

RECENT ADDITIONS

AERONAUTICS

General Theory of High Speed Aerodynamics. 1954.

ASTRONOMY

BEET, ERNEST AGAR. The Sky and its Mysteries. 1952.
GAPOSCHKIN, CECILIA PAYNE. Introduction to Astronomy. 1954.

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NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, EXECUTIVE DIRECTOR

PRINTING

Benjamin Franklin, whose birthday anniversary is observed this month, was a man of many parts but he was, first and foremost, a printer. His interest in that trade endured long after he had ceased to practice it commercially, as we know from his friendship with the English printer Baskerville and the establishment of the private printing press at Passy. There is something characteristic about the man's devotion to printing.

For the development of printing, more than any single achievement, marks the division between mediaeval and modern technologies. In form and in substance it is indicative of an epoch-making change. In its achievement we have the first instance of a process being pushed to a decisive stage in a relatively short time, notwithstanding the remoteness of the ends to be achieved. In spite of the obscurity of the records, it seems evident that the final result involved more imaginative effort and less of empiricism than had commonly been the case with inventions. The possibility of producing books at lower cost and with a higher standard of accuracy contributed decisively to the diffusion of scientific and technical knowledge, thus intensifying the effect of the new intellectual activities and contributing an essential feature to the development of modern scholarship, with its growing emphasis on written, as distinct from oral, communication and instruction.

Even apart from the less technical consequences, the new processes are significant in themselves. Printing is one of the first instances of the substitution of mechanical devices for direct handwork in the interests of accuracy and refinement in execution, as well as at reduced cost. By capitalistic methods and mass production a new and superior product was evolved. All the economic consequences of these inventions were thus characteristic of the new order; and even at the outset, the printing office showed the features of the factory enterprise rather than those of the craft shop.

With this influence of printing in view and the recollection that Benjamin Franklin was the embodiment of the new spirit, it seems most appropriate that he should have chosen printing as his trade

The Franklin Institute Museum has always provided an adequate exhibition of printing techniques and papermaking to reflect the progress made in the graphic arts, but it was felt the displays have been lacking in attractiveness. Recently, an effort has been started to make this section more attractive to the visitor without sacrificing anything

of its instruction. The room has been entirely re-arranged and already two new exhibits have been installed, with more to come. The changes promise to make the room much more attractive.

One of these new exhibits tells the story of "The Making of a Magazine" in a series of four large panels. Beginning with the basic element, paper, the exhibit shows how this is made with due attention being given to the conservation of the forests from which it is derived. The operations of the papermaking machine are graphically shown, and the various substances that contribute to produce the finished stock. Since the Curtis Publishing Company, who have sponsored this exhibit, are the publishers of several magazines that appeal to different fields of readers, something has to be shown of the great activities that lie behind the preparation of the magazines. Attention is drawn to the research that helps to provide better magazines for both readers and advertisers; to the editorial policies that control and guide this method of conveying current thought in a manner that leaves time for reflection; and to the advertising that has created in the minds of readers new desires that grow into needs and result in the purchase of goods, and which has led to the mass production that has meant lower prices and made products available to more and more people.

The manufacture of the magazine is represented by a model of the new great printing plant at Sharon Hill, and some idea of the immensity of its production is revealed in a model of a single day's printing piled in sixteen and a half columns, each as tall as the Empire State Building. The distribution of this enormous production of magazines presents formidable problems, but an idea of how they are overcome is illustrated.

These panels and the subsidiary features are gayly colored by samples of the pictures that have appeared in the magazines, the whole is brightly illuminated and enlivened with motion, It makes a truly captivating and instructive demonstration of a great industry at work. A recorded talk accompanies the visitor as he progresses from panel to panel.

Not all paper goes into newspapers, magazines, and books. One of the striking features of current merchandising methods is the stress laid upon the attractive packaging of goods offered for sale. A pioneer in the field of designing and making eye-satisfying packages is the Robert Gair Company, who have long been represented among our Museum exhibitors. They have re-designed their exhibit in keeping with the plans for giving this section of the Museum a "new look," and have succeeded in furnishing a most attractive display of folding boxes and their manufacture. Not the least interesting feature is the contrast revealed between the new and the old, not only in the boxes themselves but also in the machine on which they are made.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

TURBULENCE IN A TILTING-PAD THRUST BEARING*

BY

STANLEY ABRAMOVITZ

During experiments with a tilting-pad thrust bearing (see Fig. 1) using water as a lubricant, we found that friction torque increased abnormally when the rubbing speed exceeded what appeared to be a critical

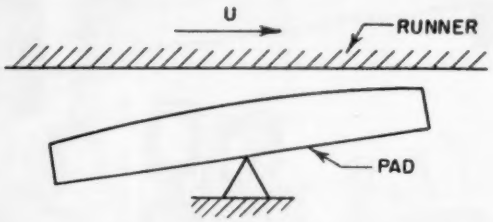

FIG. 1.

value. To examine this in further detail, tests were conducted over a range of water temperatures (75 to 200° F.) and bearing velocities (25 to 100 fps.). With the torque values obtained, a plot of coefficient of friction *versus* $\mu U/PB$ was made; its deviation from the classic, straight-line, log-plotted relationship was clear. It was interesting to find that when the plotted values were grouped by constant temperatures, the result appeared to be a family of curves with fluid temperature (viscosity) as the parameter.

Upon reviewing the literature it was found that G. I. Taylor (1, 2), had investigated fluid stability in the annulus between two concentric rotating cylinders. In applying Taylor's analysis for a film of constant thickness to a tilting-pad thrust bearing, the following relationship was derived from Newton's law of viscous flow:

$$\left(\frac{Hp}{K_2 U^3 \rho}\right)\left(\frac{Uh}{\nu}\right) = 1,$$

where Hp is horsepower absorbed; h = minimum film thickness, in.; U = velocity at mean diameter, ips.; K_2 is a constant; ρ = mass density, lb-sec^2/in.^{4}; ν = kinematic viscosity, in.^{2}/sec.

* This is an abstract from a paper that was presented at the Annual ASME/ASLE Lubrication Conference in Baltimore, Md. on October 18, 1954. It is being published by the ASME in complete form.

Since this is the equation for an equilateral hyperbola, a log-log plot of the two (dimensionless) terms in parentheses would yield a straight line whose slope is $-45°$.

Some error is introduced, in using this relationship for a tilting-pad bearing. For instance, the film thickness in a tilting-pad bearing is certainly not constant; variations in film thickness occur due to changes in speed and viscosity, and also due to pad inclination. Other points to consider are surface configuration and interrupted flow between pad segments, which do not allow strict comparison to Taylor's work with concentric cylinders. Nevertheless, using Taylor's criterion, we obtained some interesting and perhaps significant conclusions.

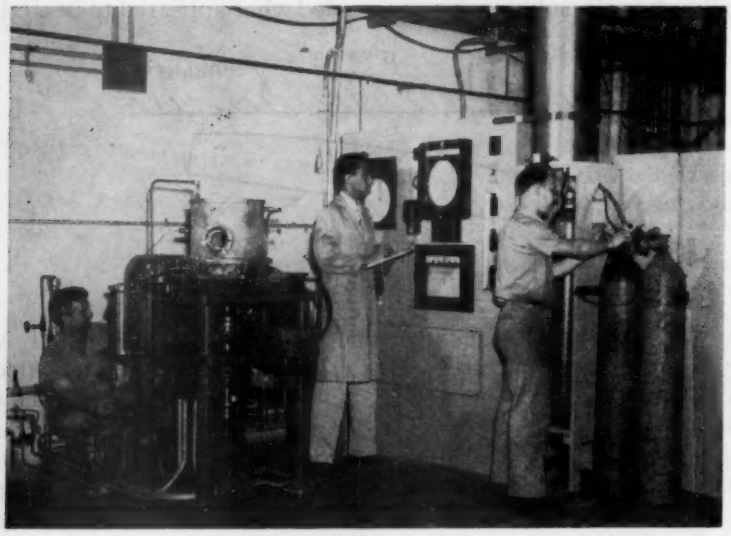

FIG. 2.

The test machine used for this research was designed and built by The Franklin Institute (Fig. 2). Using this machine, thrust bearings can be tested over wide ranges of load, speed, and fluid temperature. To obtain an accurate measure of the fluid shear between runner and pads, a rather ingenious method was derived using a hydrostatically supported disk in combination with an elastic arm and a differential transformer. The shear force and fluid temperature and pressure were continuously recorded.

The dimensionless values of the equation are plotted in Fig. 3. The experimental points follow the theoretical curve for laminar flow until a critical value of Reynolds number is reached. Above this value the horsepower increases and shows what appears to be a transition region; then the curve approaches a horizontal asymptote.

The general shape of the experimental curve is similar to the curves obtained by Nikuradse (3) from his investigation of the variation of the resistance coefficient with Reynolds number for artifically roughened pipes. Nikuradse's system of curves is dependent on a pipe roughness parameter. If a correlation can be made between the Nikuradse experiments and ours, the effect of roughness would define the final shape and magnitude of the Taylor plot above the critical value for film instability.

Figure 3 shows that the region in which film instability occurs is between Reynolds numbers 580 and 800. This can be compared with

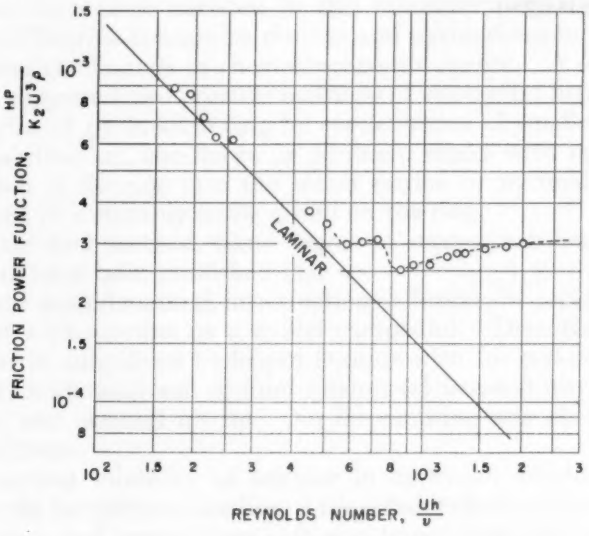

FIG. 3.

values obtained by D. D. Fuller[1] in his experiments with a journal bearing using liquid freon 11 as a lubricant; based on the rubbing velocity at which the torque started to increase abnormally, the calculated Reynolds number was about 970.

In conclusion, this investigation has shown an abnormal increase in power above a critical Reynolds number, and has indicated the presence of film instability in a tilting-pad thrust bearing. Actually, further research on this subject is needed. For this particular experiment a more variable speed range would yield a family of curves with film thickness as the parameter. It would be interesting to use different pad and runner materials (glass for example), and a fluid lubricant

[1] Professor of Mechanical Engineering, Columbia University; and Chief, Friction and Lubrication Section, Franklin Institute Laboratories.

other than water but of comparable viscosity; this would be a means of exploring the effects of adhesion, if any. Lastly, the effect of surface roughness should be investigated.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE MCDONALD, DIRECTOR

ANHYDROUS HYDROGEN FLUORIDE AS A SOLVENT FOR PURINES AND PYRIMIDINES

BY

HENRY A. RUTTER, JR.

Studies have been initiated in this laboratory upon the possible synthesis of fluorine-containing purines and pyrimidines for the evaluation of these compounds as chemotherapeutic agents. A search of the literature suggested two possible methods of synthesis: first, formation of the purine or pyrimidine ring by condensation of smaller units containing fluorine, i.e., the fluoro or perfluoro esters with urea; second, introduction of fluorine into the intact purine or pyrimidine ring by replacement of a suitably labile group on the ring.

With the first method, some degree of success has been achieved. The results have been published (1).

With the second method, introduction of fluorine by replacement was attempted with adenine as a model compound. Diazotizations were carried out in anhydrous hydrogen fluoride with (*a*) powdered sodium nitrite, (*b*) boric acid and sodium nitrite, (*c*) isoamyl nitrite, and (*d*) boric acid and isoamyl nitrite. No fluoropurine was obtained under these conditions.

The marked solubility of adenine in hydrogen fluoride, however, suggested the further examination of the solvent effect of this medium on other purines and pyrimidines. It was hoped that the investigation would furnish criteria for a second method of replacement of labile groups with fluorine, namely, the cleavage of labile thioethers of uracil in anhydrous hydrogen fluoride. It is known that these thioethers undergo smooth acid catalyzed hydrolysis with aqueous hydrochloric acid. Although no cleavage of thioethers by hydrofluoric acid had been found to occur to date, a preliminary investigation does indicate this possiblility.

Anhydrous hydrogen fluoride, purchased from Matheson, Coleman & Bell, was distilled from the tank which had been fitted with a cooled copper coil. The cooling coil was flushed thoroughly and 40 ml. of the liquid were collected in a polyethylene bottle containing 5 g. of the previously dried purine or pyrimidine. The liquid was kept below 0° by surrounding the bottle with dry ice. Tests indicated that the hydrogen fluoride contained no copper fluoride as contaminant nor was any present in the compounds on recovery.

The compounds dissolved almost at once and were soluble to the extent of at least 12.5 per cent.

Purines: Adenine and guanine formed hydrofluorides which were isolated by evaporation of solvent. The original purines were recovered as hydrochlorides by treatment with calcium chloride. Uric acid was recovered unchanged from the hydrogen fluoride solution by evaporation of solvent and recrystallization in water.

Pyrimidines: Thymine, uracil, 2-thiouracil, 2-benzylmercaptouracil, and 2-benzoylmethylmercaptouracil could be recovered unchanged by evaporation of solvent and thoroughly washing with water or by recrystallization from boiling water to remove occluded solvent. None of the pyrimidines underwent chemical change upon gentle reflux in hydrogen fluoride with the exception of benzoylmethylmercaptouracil which apparently suffered rearrangement upon 24 hr. reflux. The new compound, Mp. 238–239°, which has an elemental analysis identical with the starting material, but differs in properties, is under investigation.

The rearrangement of the thioether of uracil is difficult to interpret. Two other investigators (2,3) have published papers on the use of non-aqueous cleavage reactions applied to pyrimidines. It is hoped that further work in this laboratory will demonstrate the applicability of hydrogen fluoride in this type of reaction.

The solvent should be an ideal non-aqueous medium for chemical reactions carried out on these compounds at low temperatures. Katz (4) recently reported the use of anhydrous hydrogen fluoride as a reaction medium for biologically important proteins including hormones and enzymes.

Hydrogen fluoride has been found to be an excellent solvent at low temperature for purines and pyrimidines.

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ONE HUNDRED YEARS AGO IN THE *JOURNAL*

It was the custom in the middle of the nineteenth century to publish in the JOURNAL OF THE FRANKLIN INSTITUTE the specifications of new steamships. As an example, the following description is reprinted from p. 57 of the January 1855 issue.

Particulars of the Steamboat Cuba.

Hull built by Samuel Sneden, Greenpoint, L. I.; Machinery by Pease & Murphy, New York; Intended service, Mobile to New Orleans.

HULL.—

Length on deck, from fore part of stem to after part of stern post, above the spar deck,	250 feet.
Breadth of beam at midship section,	32 " 8 inches.
Depth of hold,	9 "
Draft of water at load line,	6 " 6 "
" " below pressure and revolutions,	6 "
Tonnage, custom-house,	800.
Masts and rig,	foresail and jib.

ENGINE—Vertical beam.

Diameter of cylinder,	56 inches.
Length of stroke,	10 feet.
Maximum pressure of steam in pounds,	80.
Cut off,	$\frac{3}{4}$.
Maximum revolutions per minute,	18.

BOILER—One—Flued.

Length of boiler,	35 feet.
Breadth "	13 " 9 inches.
Height " exclusive of steam chimney,	13 " 3 "
Number of furnaces,	3.
Breadth of "	3 " 8½ "
Length of grate bars,	7 " 8 "
Number of upper flues,	6.
Internal diameter of flues,	19 and 21 ins.
Heating surface, (fire and flues,)	1700 sq. feet.
Diameter of smoke pipes,	5 feet.
Height "	36 "
Description of fuel,	wood.
Combustion,	Natural draft.

PADDLE WHEELS.—

Diameter,	30 feet.
Length of blades,	8 "
Depth "	2 " 2 inches.
Number "	28.

***Remarks.*—Floor timbers at throat, *molded*, 15 inches;—*sided*, 5 inches;—distance of frames *apart at centres*, 24 inches. Frame strapped with diagonal and double laid iron straps 4 by ½ inch. C. H. H.**

This steamer was intended for coastwise service and therefore was of shallow draft. It was otherwise about as large as the *Ariel* (described on p. 285 of the April 1855 issue), which was intended for trans-

atlantic service from New York to Liverpool. By contrast the January 1855 issue (p. 56) also contained the following description of

The Mammoth Steamer of Great Britain.

The following comprise most of the essential elements of this monster iron vessel, building by Messrs. Scott Russell & Co., for the Eastern Steam Navigation Company:

Length,	675 feet.
Beam,	83 "
Depth of hold,	60 "
Draft of water at load line,	30 "

This vessel is to be propelled by four steam engines, two of them connected with side water wheels, and two with a screw propeller.

The water wheel engines are to be of 1000 horses; oscillating cylinders, 74 inches diameter, by 14 feet stroke of piston.

The screw engines are to be of 1500 horses, 84 inch cylinder, and are to be made by Messrs. Bolton & Watt.

The boilers will have 100 furnaces.

The hull is divided into water-tight compartments of 60 feet. The weight of plates will be 10,000 tons, and the number of rivets 3,000,000. The plates at bottom are to be one inch thick, and three-quarters at sides and top.

The frame is to be plated within as well as outside the ribs, up to the water line.

Water wheels are to be 60 feet in diameter.

Vessel to accommodate 600 first class and 2000 second and third class passengers, and to carry 12,000 tons of coal. C. H. H.

BOOK REVIEWS

BIOLOGICAL EFFECTS OF EXTERNAL RADIATION, Volume 2, edited by Henry A. Blair. 508 pages, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $7.00.

Biological Effects of External Radiation is still another notable volume of the National Nuclear Energy Series which was planned to serve as a record of research accomplished under the Manhattan Project and the Atomic Energy Commission. Although the Manhattan Project was assigned by the Corps of Engineers of the War Department with the primary objective of utilization of atomic energy for military purposes, many aspects of fundamental research in the field of radiobiology were investigated. This book represents the major part of the work done at the University of Rochester during the war period and includes a collaborative study of the chronic effects of neutron irradiation with the Biochemical Research Foundation at Newark, Delaware.

The book is a report of the research done under the supervision of the 21 contributing authors and is organized into 17 chapters (actually 17 original articles). It is divided into three parts as follows: Part I, Single doses of whole-body X radiation (8 chapters, 203 pages); Part II, Chronic X radiation (7 chapters, 193 pages); Part III, Fractionated doses of fast neutrons (2 chapters, 94 pages).

Part I describes the biological effects of single acute exposures of X radiation upon dogs, rats, hamsters and monkeys. The findings give an estimate of the variations that exist among these mammals and supplement related research as reported in the literature. Although specific application of data upon these mammals to man is uncertain, an estimate of his relative sensitivity should be within the range of these animals. The pathologic changes in rats exposed to whole-body radiation of single doses of 550 r were recorded as demonstrated in the histological examination of many tissues and organs. Described are marked effects of X radiation on many tissues such as lymphatic and bone marrow. Other tissues were shown to be affected to a lesser degree and some, such as kidney, lung, liver and bone, not at all. As reported by other workers, it is again noted that the lymphocytes are the most radiosensitive cells of the body. One of the first biological effects noted in a blood examination as a result of X radiation is a drop in the peripheral lymphocyte count. However, lymphatic tissue also has a remarkable capacity to recover rapidly from radiation damage. Also described with the full use of tables, graphs and illustrations are spermatogenesis and the changes occuring in the epithelial cells of the mucosa of the gastrointestinal tract as a result of X radiation.

Time and again it is noted that even the most significant findings depend upon accurate statistical analyses for the interpretation of experimental results. For instance, it will come as a surprise to many to know that as small a dosage as 5 r produced a highly statistically significant depression of the lymphocytes. This tends to come uncomfortably close to the so-called maximal "tolerable" or "permissible" dose of 0.3 r per week which is generally recognized as the standard for humans in this country. But it is also revealed that radiation experiments indicate that hematological examinations are unreliable in low dosages and in individual cases once radiation damage occurs.

In cross-circulated blood experiments upon X radiated cats, data are presented which constitute the first observations on animals in which rate of blood platelet utilization—not platelet life span—have been directly measured. Unlike the erythrocyte, the platelet is destroyed when used, hence data obtained on the rate of disappearance of transfused platelets represents essentially evidence of platelet demands of the body. Experi-

ments disclosed that the entire platelet mass is replaced every 2–5 days which is probably the same for the normal animal. Many conflicting reports appear in the literature on the question of whether or not there is an indirect effect of X radiation in tissues of the body which are far removed from the region being X radiated. In cross-circulation blood experiments performed between normal, non-radiated cats and X radiated ones, results do not support the thesis of indirect effects peculiar to X radiation.

Experiments were performed to test the validity of the linear relation of mutation frequency to X ray dose in the fruit fly, Drosophila, in which it was reported that with dosages as low as 50 and 25 r, the linear relationship of dose to mutation frequency holds. In a comparison of X and beta radiation effects in rabbits it is reported that from 3–5 times the dosage of beta rays is necessary to produce a given effect.

Part II, which is concerned with chronic X radiation, presents observations on rats, dogs, monkeys, rabbits, mice and fruit flies exposed to whole-body X radiation in divided doses over long periods. Low daily dosages of 0.1, 0.5, 1.0 and 10 r were given to the mammals and the biologic effects noted for a period of about 2½ years. Worthy of note is the estimate of relative sensitivity to X radiation. The rat, dog, and mouse are approximately of equal radiosensitivity to chronic X radiation with the rabbit appearing more resistant and the monkey somewhat more susceptible to radiation. Since monkeys are difficult experimental animals and easily succumb to respiratory ailments, this reviewer wonders if these factors may have been a contributing factor. The fact that marked differences exist in hematological responses of dogs and rabbits exposed daily to the same doses of X radiation should serve as a warning to those who would apply data on laboratory animals to humans. But this reviewer cannot refrain from advising physicians who do fluoroscopic and radiologic work to view with considerable respect the observation that among the X radiated animals, the number of cases of leukemia increased with the dosage, leukemia even detectable (1%) with dosage as little as 0.1 r per day; up to 12% with 10 r per day.

In research upon the radiation effects on human finger ridge detail in which an ingenious impression compound was employed to record the dermatoglyphics, conclusive evidence shows the high degree of professional groups such as radiologists, orthopedists, fluoroscopists and dentists who receive radiation damage on the fingers. Unfortunately not included in the volume is the Sonnenblick *et al* (1951) survey of 63 fluoroscopic units as used by physicians in which it was found that the fluoroscopes gave on the average 26.6 r per minute with 12 having an output of more than 30 r per minute. Indeed one unit as measured in air at table-top had an output of 118 r per minute! Although the majority of physicians in the study were diplomates, none knew the dosage administered in r/minute of his fluoroscopic unit.

Part III presents the research upon fractionated doses of fast neutrons as produced by the cyclotron at the Biochemical Research Foundation, Newark, Delaware. The lower dosage levels used produced no observable clinical effects in the rats, rabbits and dogs but pronounced clinical changes were described in those animals receiving the higher dosage. Data show species differences in response to neutron radiation and the various types of neoplastic diseases which were found to be more common in the neutron-radiation exposed rats than in controls. This reviewer notes that response to chronic neutron irradiation is similar in at least to one striking observation as reported for acute and chronic X radiation as given in other chapters of the book: the marked reduction in the number of lymphocytes in the peripheral blood.

This valuable book, which represents the original research endeavors of hundreds of scientists, technicians and others is almost certain to be a widely referred to work even where specific data are needed in evaluating the biological effects of external radiation.

Throughout the book—almost like a persistent and recurring background melody —it is apparent that even small, repeated dosages of radiation can show a biological effect in the irradiated animal. But what is not clearly apparent are the effects of very low but long-continued, successively repeated dosages which may be seemingly tolerated

by an animal during its natural life but which may affect the sensitive genes in the germ plasm. It is an established fact that in many laboratories throughout the world, radiation has produced alterations in heredity in a wide variety of plants and animals. These gene mutations, most of which are deleterious, occur in future generations of the irradiated organisms. Since man's germinal cells are not unlike those of many experimental animals, one must view with considerable apprehension the possible biological effects in man's descendants when even extremely small dosages of irradiation are delivered to him in this atomic age.

An enormous amount of valuable information has been compressed within the pages of this excellent volume. For the convenience of the reader, abstracts or summaries are given for most of the chapters, each of which contains a bibliography.

In no small measure, this work has extended knowledge of biological processes as a result of radiation and should serve not only to inform the general reader and specialist but also stimulate additional investigation in this exciting field.

RALPH WICHTERMAN

ELECTROACOUSTICS, by Frederick V. Hunt. 260 pages, drawing, 15 × 22 cm. Cambridge, Harvard University Press; New York, John Wiley & Sons, Inc.; 1954. Price, $6.00.

Electroacoustics by Frederick V. Hunt is Number 5 of the Harvard Monographs in Applied Science. This reviewer had the opportunity to review the first of these monographs, "Matrix Analysis of Electric Networks" by Philippe LeCorbeiller, when it was published in 1950. Since that time three new members have been added to the editorial committee, and the series seems to be progressing at better than one book a year.

In the first volume the editorial committee stated that "The Harvard Monographs in Applied Science are designed to provide a medium for publishing the results of University research to a wider audience than would be reached by individual professional journals." The use of the word "research" in this case should perhaps be explained so that the real nature of these monographs will be clear. In each of these monographs the writer has made a study of the latest developments in his subject field and has presented the formal results of this study. The results of the study are preceded by an historical review of developments leading to the contemporary contributions. The work is then a study rather than an experimental research undertaking where new knowledge is derived from the author's laboratory investigations.

A little more than the first third of Frederick Hunt's book is devoted to the historical review. The remaining chapters of the book develop analyses of various transducer systems using as examples well-chosen, modern devices. One example of interest is the ring-armature receiver which was pioneered at the Bell Telephone Laboratories and first publicly described in 1951. A second electroacoustic transducer which for a long time remained a laboratory curiosity, but has within the past year gained commercial standing, is the electrostatic loud-speaker. In fact, one of the largest radio manufacturers has started producing an electrostatic speaker for use in home instruments.

Magnetic, electrodynamic and electrostatic transducers associated with acoustic devices are analyzed. The analysis generally employed takes the form of a circuit representation of electrical and mechanical parts. Mechanical parts are assigned equivalent electrical analogs so that the entire transducer as well as its driving point and load impedances may be shown in a single circuit. The circuit is then subjected to conventional electrical procedures of analysis, and the results translated in terms of mechanical action, if this is to be the desired result.

The author demonstrates considerable facility in making the electro-mechanical analyses which he uses for illustrative purposes. If the reader follows carefully the mechanical-to-electrical transformations and vice versa, he should acquire some ability in attacking certain other instrument problems, even outside of the field of acoustics.

C. W. HARGENS

FIBERGLAS REINFORCED PLASTICS, by Ralph H. Sonneborn. 240 pages, diagrams, illustrations, 14 × 22 cm. New York, Reinhold Publishing Corp., 1954. Price, $4.50.

Plastics reinforced with glass fibers have greater strength, stiffness, impact resistance and dimensional stability. This unique phenomenon has opened new aspects to the plastics industry. After ten years of its existence, Fiberglas-reinforced plastic has found widespread application as a new structural material. This new industry has advanced so fast that engineering data and fundamental knowledge of the properties of these materials lag far behind their application by progressive designers and manufacturers. This book makes a successful attempt to compile the available knowledge and experience on this subject in a way that it can be readily put to use by the professional engineers.

Avoiding all unnecessary details, the book familiarizes the plastic engineer with the subject in a shorthand style. After discussing the general nature and uses of fiberglas-reinforced plastics, the properties of the components (fiberglas and resins) are discussed separately. Although fiberglas and the polyester-type resins have been used together almost exclusively in the past, there are a number of other resins such as epoxy resins, phenolic resins and others which might gain considerable importance in the future.

A number of molding procedures are available; the process used in any given instance is determined by the type of reinforcement to be used, the size and shape of the product, and the number of parts to be produced. In many cases it is desirable to form a mat of intricate shape directly out of chopped strands, rather than using prefabricated mats cut to size and fitted together. This method has become known as preforming and the author discusses several preform processes. The book also contains valuable hints with respect to secondary operations such as punching, shearing, drilling, etc. The chapter on properties of fiberglas-reinforced plastics presents the available data in well ordered and easily readable tables. The designer will find many hints based on practical experience as well as many inspiring examples of applications.

The second part of the book is devoted to the development of a design theory based on assumptions, the validity of which, as the author himself remarks, is open to question. Consequently the design procedures he has worked out are subject to modifications as more experimental data become available.

The book, in good type and well equipped with excellent photographs and illustrations, will undoubtedly become a valuable reference for the reinforced plastics industry.

KARL SITTEL

SUCCESSFUL COMMERCIAL CHEMICAL DEVELOPMENT, prepared by the Commercial Chemical Development Association with H. M. Corley as Editor-in-Chief. 374 pages, illustrations and charts, 16 × 24 cm. London, Chapman & Hall, Ltd.; New York, John Wiley & Son, Inc.; 1954. Price, $7.75.

This study in management control methods meets the objective as stated in the *Foreword:* "To document in one volume the most enlightened, present-day knowledge of the important principles of every essential step, as well as the pitfalls to be avoided, in selecting promising new chemicals and rapidly developing them to the stage of economic importance."

The presentation is unusual, in that the twenty-one chapters have been written by different committees. These committees were set up by the Commercial Chemical Development Association, which is an organization of experienced personnel in chemical industry having responsible charge of some phase of commercial development. The more than 100 contributors include representatives of almost every large chemical company. Further assurance that the book would represent a true cross-section of the industry was gained by having the manuscript scrutinized by an anonymous review board. The smoothness of the final product of so many craftsmen attests to a superb job of editing.

The book opens with a short historical review of the rise of chemical industry in the United States. Then several chapters are devoted to delineating the scope of the contributions to commercial development of

a new product that are made by the various departments of a company—engineering, marketing, sales, legal, for instance. The middle third of the book is concerned with the role of management in keeping track of the progress of a new product through what are normally the four phases of its development: pre-pilot plant stage, process development, semi-works stage, and the period while awaiting full-scale development. The reader is shown how the responsibillty for the whole array of essential activities in the development of a new product may be distributed among the departments of the company. Finally, some of these activities, such as sampling, pricing, advertising, and safety, are discussed in separate chapters.

This book appears at a time when the concept of an integrated operation for commercial chemical development is just coming of age. The trend since 1945 has been toward concentrating in an autonomous group reporting to top management the co-ordination of all the activities in commercial chemical development. The thorough analysis of the functions of such a group given by this book may well help spread this philosophy of management.

The influence of this book should extend beyond the chemical industry. Management personnel in chemical companies and students training for careers in chemical industry will naturally profit from it. But the non-chemist interested in business management can also learn a great deal from it. He can see the ramifications of the management operations that underlie the successful experience of the chemical industry. This should make it possible for other industries to adopt with profit some of the same techniques of management that have helped the chemical industry become preeminent in the speed with which new discoveries are fully commercialized.

JOHN S. BURLEW

ASTROPHYSICS, Vol. 2, NUCLEAR TRANSFORMATIONS, STELLAR INTERIORS, AND NEBULAE, by Lawrence H. Aller. 291 pages, diagrams, 16 × 24 cm. New York, The Ronald Press Co., 1954. Price, $12.00.

The companion volume to the authoritative "Astrophysics, Atmospheres of the Sun and Stars" is now available. Dr. Lawrence H. Aller, Associate Professor of Astronomy at the University of Michigan, has presented what is essentially an extrapolation of information which astronomers have so laboriously acquired from the direct observation of the organized material in the universe, the stars, to the unorganized material such as bright and dark interstellar nebulae, novae and supernovae and the erratic variable stars.

The wonder of any work on astrophysics is the searching analysis which permits the astronomer to synthesize the structure of a star—from the center to the outer atmosphere—when so little of the star can be penetrated with an optical telescope. Actually the depth to which we see corresponds to a point high up in our atmosphere where the pressure is less than ⅕ of 1 per cent that of sea level atmosphere.

Essentially the problem resolves itself into the following: Knowing, from physical measurements, the dimensions, luminosity and spectrum of a star—what can be deduced about the internal composition of this body? For this analysis the chemical composition must be assumed for a particular model, as on this parameter depends the energy generation mechanism of the stars. The author states: "The hydrogen consumption rate will depend on the amount of hydrogen and, for stars that operate on the carbon cycle, the initial amounts of carbon and nitrogen, since the latter cannot be built up from the lighter elements."

In Chapter I, dealing with "stellar interiors and nuclear transformations," the student is led through those properties of matter and radiation which pertain to the general problem of stellar interiors. In this chapter is found an excellent explanation of the "liquid drop" model of the nucleus of the atom.

"Model Stars" is covered in the next chapter. This begins with a description of the convective model in which energy is carried to the surface by large-scale convective currents and the Eddington standard model in which the energy flow is by radiation through the entire star. The evolutionary trends of the giant stars and the explanation for dwarf stars is contained herein.

Chapter III deals with "the Cepheids and long-period variable" stars. Here the author

uses the study of the pulsating stars to yield a picture of stellar interiors which is unobtainable from objects in static equilibrium. The study of these variables is one of the most important facets of modern astronomy.

The next chapter is on "Stars with Extended Envelopes" of which the most important class is the catastrophic novae and supernovae. In Fig. 9 is shown a model of a nova outburst. In this model an attempt has been made to account for the complicated spectral, velocity and temperature changes common to the nova outburst.

Chapter V deals with the curious and rare planetary nebulae. Slightly more than 100 are known but they represent an important class of objects for these are gas clouds shining by degraded ultra-violet radiation of the exceedingly hot central stars. Their physical details are carefully reported.

The last chapter deals with the interstellar medium. This is the unorganized material which in mass is equal to the total star population. Here we find the new techniques used in radio astronomy. Reference is made to the 21-cm. radio emission used to trace out the spiral arms of the Galaxy due to the radiation from the hydrogen clouds found there. The effect of the interstellar medium or light passing through it is covered as is the density, composition, distribution and temperature.

Astrophysics fills an important need in the library of the astronomer. This comprehensive and authoritative work will prove of inestimable value to the graduate student.

I. M. LEVITT

HIGHWAY ENGINEERING, by Laurence I. Hewes and Clarkson H. Oglesby. 628 pages, diagrams, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $8.00.

When one thinks of highway engineering, he usually thinks of the design of road surfaces, of bridges, of drainage and proper subgrade. Seldom is he apt to think of highway financing, traffic surveys, human responses in driving automobiles and of the many other factors that comprise the broad field of highway engineering. *Highway Engineering,* written by L. I. Hewes, late Chief, Western Headquarters of the U. S. Bureau of Roads, and C. H. Oglesby, Professor of Civil Engineering at Stanford University, covers all these many subjects. At a stage when highway construction is at a peak and still increasing, such a book is very timely. It is extremely interesting, too, to learn all the ramifications that are involved in the construction of a highway.

The first part of the book is concerned with the planning, economy and financing of highways. Involved in planning are such items as traffic surveys and road inventories; in economy, cost of motor vehicle operation, accident costs and costs of highways; and in financing, such items as responsibility for highways, sources of funds and means of accelerating road improvement. The large portion of the book is concerned with the standard items of highway enginering, that is, the design of the road bed and surface. Here are discussed highway design—the actual layout of the route and grades; proper ways of drainage; the subgrade structure; gravel and crushed rock roads and how they are stabilized. The various types of road surfaces, such as macadam, bituminous and cement, are all explained, and the methods and formulas for the design of concrete pavements are given. The book is concluded with a description of highway maintenance.

Highway Engineering is written for the junior or senior level in college. It should prove to be a very fine text. It should also be valuable to anyone in the highway phase of civil engineering because it has under one cover all the details of highway engineering.

E. W. HAMMER

THE THEORY OF THE PHOTOGRAPHIC PROCESS, edited by C. E. Kenneth Mees. Revised edition, 1133 pages, diagrams, illustrations, 16 × 24 cm. New York, The Macmillan Co., 1954. Price, $21.50.

Because of the tremendous strides that have been made in photographic science during and since World War II, Dr. Mees has found it necessary to revise *The Theory of the Photographic Process,* rewrite considerable portions, and to add welcome new chapters: "The Action of Charged Particles on the Photographic Emulsion," "The Latent Image Produced by X-Rays" and "The Sensitometry of Color Films and Plates."

The new and rewritten material retains the clear, orderly and logical approach to each subject that distinguished the earlier edition. The historical background in each chapter is still very complete and well documented in spite of the statement in the preface that much of the historical material in the first edition has been omitted to make room for new data.

Dr. Mees and his collaborators have performed an outstanding service in presenting and bringing up-to-date so complete and comprehensive a handbook on so complex a subject in such easily readable form. The scientific worker who uses photographic materials for making his measurements will find here all the information he needs for a clear understanding of the processes involved. *The Theory of the Photographic Process* can also be recommended strongly to the serious amateur photographer whose curiosity about the photographic processes is left unsatisfied by the popular photographic magazines.

L. P. TABOR

CONCEPTS OF SPACE—THE HISTORY OF THEORIES OF SPACE IN PHYSICS, by Max Jammer, with foreword by Albert Einstein. 196 pages, 15 × 22 cm. Cambridge, Harvard University Press, 1954. Price, $3.75.

The conventional review has been unkindly characterized as "an unnecessary preamble to an unheeded plea" to buy a book and place it proudly on your shelf. In these comments no such request is made, as this is not the next volume which you should purchase, that is, unless you are trained in the philosophical discipline and then you will have ample opportunity to read of its impressive merits in more specialized journals.

There is, however, good reason to signal the publication of Max Jammer's *Concepts of Space* in these pages as it is magnificent proof of the vigor and success of the Harvard school of history of science. In Cambridge, even before the great Dr. George Sarton came at the end of World War I, there has always been a strong tradition in this field where the humanities and the sciences meet, as they must meet for the continued balanced development of our kind of civilization.

This book was written by Dr. Jammer while Visiting Lecturer at Harvard on leave from his duties at the Hebrew University in Jerusalem where he teaches physics and history of science. No greater testimony of the advantages to the entire intellectual community of such interchange of ideas is needed. In *Concepts of Space* we now have the first comprehensive, well-documented analysis of physical space theories, ancient and modern.

It is significant that Dr. Einstein has written the foreword, for he more than any other has made all educated people conscious that something ails the old "absolute space" notion, even if it seems sound enough for everyday use. It is also worth noting that Dr. Jammer expresses his indebtedness to Professors Sarton, I. Bernard Cohen and H. A. Wolfson for they represent the strongest single block of workers in the history of scientific ideas. In the words of the English scholar, Charles Singer, "Dante called Aristotle 'the master of those who know.' Sarton who comes some 2300 years later, is among the rare few who are not wholly unworthy of that title, for he seeks to bring into the world of thought a unity which it has lost." Dr. Max Jammer is clearly cast in the same mold and has already done his share towards the same end, with promise of far more fine work to come.

If you do buy *Concepts of Space* you will recognize immediately that the concise and lucid style saves this compression of the history of a basic but elusive feature of all complete physical systems from being impenetrable for the layman. The fact is, the layman can here see a singularly powerful mind in action even if the subtler arguments escape him.

J. W. STREETER

ANALOG METHODS IN COMPUTATION AND SIMULATION, by Walter W. Soroka. 390 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $7.50.

This book covers a wide range of material in the field of analog computation. In fact, in this day of large scale electronic computers, some of the material presented in

the later chapters is not given much thought by the engineer working in the computer field.

The first two chapters are devoted to the description of various mechanical, electromechanical, electrical and electronic computing elements. There is no attempt to present detail designs, but merely to explain the general principles of various types of adders, integrators, etc.

The next two chapters show how the basic components can be connected to solve linear and nonlinear algebraic equations. In addition to the conventional simultaneous equation solvers, there are descriptions of some special purpose computers. An example of the latter is a section devoted to the solution of secular equations, that is, computing the natural frequencies of a linear oscillating system. The author's development here is carried out nicely, showing first how the equations can be solved by the trial and error adjustment of potentiometers, and then secondly, how the computation can be mechanized for automatic operation.

Chapters 5 and 6 cover the subjects of the mechanical and electronic differential analyzers. In these chapters, it is shown how the basic components described in the beginning of the book are used to solve ordinary differential equations. There is also a short section describing the application of the mechanical differential analyzer to the solution of partial differential equations. In addition to the general principles of mechanization, there is a discussion of scale factors —both amplitude and time wise.

The chapter on dynamical analogies is rather comprehensive and gives many illustrations of the electrical circuit equivalents to mechanical systems.

There is a chapter which covers the finite difference approach to the solution of ordinary and partial differential equations. In this discussion it is shown how the differential equation is converted to a finite difference equation and then the network analog of the latter is constructed. The last chapter shows how partial differential equations can be solved by continuous methods using membrane or conducting-sheet analogies of the physical system.

In general, this book is quite comprehensive in its coverage of the analog computing field. Naturally, where such a large field is covered, there are many topics which can be touched upon only slightly. However, the author makes up for this by referring to many of the detailed technical articles appearing in the journals.

IRVING GLASSMAN

MOLECULAR THEORY OF GASES AND LIQUIDS, by Joseph O. Hirschfelder, Charles F. Curtiss, and R. Byron Bird. 1219 pages, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $20.00.

This treatise, twelve hundred and some pages in length, surveys the entire field involving the properties of gases and liquids from a unified viewpoint and in a consistent notation. The authors state that the book is a partial answer to the request of the Research and Development Board for a report on the present status of research in the fields of the equation of state and transport phenomena. It has grown out of studies undertaken in the Bumblebee program sponsored by the Bureau of Ordnance. The authors acknowledge the contributions of many people, especially the staff of the University of Wisconsin Naval Research Laboratory and others of the Johns Hopkins University Applied Physics Laboratory.

A concise statement of the scope is found in the preface:

"The subject material in the book is divided into three parts: equilibrium properties, non-equilibrium properties and intermolecular forces. The basic problems associated with each of these fields are discussed in Chapter I. In the last part of that chapter there are presented for ready reference some results of classical and quantum mechanics which are used throughout the book. Part I (Chapters 2–6) begins with a survey of equilibrium statistical mechanics, which serves as the basis for the theoretical development of the equation of state. Two main applications of the theory are then discussed—the prediction of the p-V-T properties of gases and liquids, and the analysis of experimental equation of state data to obtain information about intermolecular forces. Part II (Chapters 7–11) is a discussion of non equilibrium statistical mechanics (kinetic

theory) and the theory of transport phenomena. Whenever possible this treatment parallels the discussion given in Part I. This is, the prediction of the bulk properties and the methods of obtaining information about intermolecular forces are considered. The second part of the book is concluded with a chapter on hydrodynamic applications, which contains a unified discussion of the propagation of sound waves, flames, and detonations. Part II (Chapters 12–14) deals with the electromagnetic and quantum mechanical theory of the forces between molecules, atoms, ions and free radicals. Here the a priori quantum mechanical calculations of intermolecular forces are compared with the information obtained in the first two parts by the analysis of the experimental data on bulk properties."

Students of chemical physics, experimental physical chemists and those interested in statistical mechanics and theoretical chemistry should all find the book useful. Problems for students, sample calculations for designers and extensive tables with numerical examples to illustrate their use and many mathematical appendices are included. Chemical, author and subject indices, very essential to a volume of this size, are well done. The text is well documented with references. It has taken considerable time and effort to unify and organize the material for this book, but the result will be long lasting. The paths for future research should be more clearly evident to those who explore these pages. WILLIAM E. SCOTT

STRENGTH AND RESISTANCE OF METALS, by John M. Lessells. 450 pages, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $10.00.

The appraisal of a metal in its application to machines and structures is dependent on the proper interpretation of various physical tests. Applied metals research or the mechanics of metallurgy is of great importance in industrial developments. Professor Lessells has a matured and authoritative background in this phase of engineering and, therefore, this work is of particular value to all engineers and metallurgists engaged in the engineering research of metals.

The work is a considerable extension of Part II in Timoshenko's and Lessell's treatise on "Applied Elasticity." The first part covers the basic properties of metals as interpreted by their tensile properties. The author carefully defines the elastic and transition stages, the plastic and breaking stages, and the nature of ductile (or sliding) and brittle (or separation) failures. The interpretation of test specimens, effects of gage length, contraction of area, and apparent and true stress relations are also carefully discussed. The properties of steel are discussed, showing the effect of carbon on yield and ductility as interpreted from tensile stress-strain relations.

"Elastic-Stage Modification" covers the effects of overstrain, cold drawing, annealing, and the resulting residual stresses. The effects of these items on yield and hysteresis are discussed in conjunction with cyclic stresses. The author differentiates residual stresses into micro and macro stresses. Succeeding chapters discuss the now important subject of tensile properties at elevated temperatures, in a comprehensive manner. Creep-time curves under various stress and temperature conditions are shown, as well as an outline of creep testing equipment. The chapter on hardness gives one a real understanding of the significance of the hardness test.

The chapter on impact testing introduces a complicated research subject. The significance of fracture energy for ductile and brittle materials and the notched bar tests are covered in some detail. An interesting discussion is given to crack formation and propagation in conjunction with ductile and brittle materials.

The chapters on the fatigue of metals are of particular value and comprehensive. Firts, the S-N diagram is clearly described; second, compound stresses, with the various stress theories, are correlated with the fatigue or cyclic stress interpretations; and third, in the stress cycle, the mean and the stress range are defined along with a good discussion on the Goodman and Gerber stress-range criterion. This is followed by interpretation of test data on various materials. The remaining discussion on fatigue is devoted to a very comprehensive discus-

sion on controlling factors, such as stress concentration, fillets, surface conditions, corrosion, the effect of peening and cold rolling, and fretting surfaces in contact.

The last chapters are devoted to a research discussion on the nature of fracture of metals and strain hysteresis. Finally, the important subjects of strength theories and working stresses are discussed.

The only suggestion for a possible addition in a later edition of this work is a general discussion on the fatigue properties of welded connections.

Unlike most books on strength properties of materials, the author includes a group of selected problems that should prove of real value for a better understanding of the subject.

The author is to be congratulated on an important contribution to the mechanics of metallurgy. In this connection, it is interesting to note that the author received the Levy Medal of The Franklin Institute for his paper "Combined Stress Experiments on a Nickel-Chrome-Molybdenum Steel." *

RUPEN EKSERGIAN

* JOHN M. LESSELLS AND C. W. MACGREGOR, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 230, p. 163 (1940).

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

CURRENT TOPICS

Diesel-Electric Trains for the Yukon.—Surprised teams of huskies and perplexed herds of caribou may stop in their respective snow tracks this winter at first sight of what should be the fastest moving ground objects in the Yukon—two diesel-electric locomotives. Built by the General Electric Company to cope with the most punishing conditions on the continent, the new locomotives will be operated by the White Pass and Yukon Route between Skagway where temperatures reach 80 degrees above zero in the summer to Whitehorse, Canada where they drop to 65 degrees below zero in the winter.

In just 20 miles, the locomotives must pull their loads from sea level at Skagway to an elevation of 2,885 feet at the summit of White Pass. They are the first diesel-electric locomotives to be used in the Yukon.

For purposes of heating and crew comfort, each locomotive has a box-type cab. With this structure, apparatus in the engine compartment has a larger air cushion between it and the engine hood than would be found in a regular road switcher. The extra air permits heating by radiation from the engine and accessories. A box cab also enables the fireman to reach all power plant and control apparatus without having to encounter the outside elements.

Each 80-ton diesel-electric is expected to pull 260 tons compared with 160 tons by the steam engines now in service. Average grade for the first 20 miles from Skagway is 2.6 per cent, with a maximum grade of 3.9 per cent.

Winterization of the locomotives includes insulating all outside piping, applying additional operating cab insulation, pre-heating fuel, re-circulating engine radiator air, additional heating of engine cooling water during periods of engine idling, and extra protection of storage batteries by heating the battery box air.

Although the locomotives are equipped with double-thick plows, capable of tossing aside several feet of accumulated snow, a rotary snow plow must precede the train. At that, the rotary must be run close enough to be visible or the track is apt to be reburied in certain places along the route. Snow depth on top of the mountains above Skagway measures 40 feet and the two-story station at White Pass Summit has been known to literally become part of a snow drift.

Originally constructed in 1900 to implement the Klondike gold rush, and relied upon in the early 1940's to haul equipment for the Alaska Highway, the White Pass and Yukon today serves the 10,000 inhabitants of the Yukon (a population which has doubled since World War II) and is the prime carrier of base metals out of the region. Many supplies needed for gold mining are shipped by rail, although most of the gold mined in the territory is flown out.

The road also hauls much of the asbestos fibre, lead, zinc, silver, and cadium ore for shipment to the United States and Canada for processing. In addition, military construction materials and supplies form an appreciable part of the haulage.

New Control Instruments.—Two new instrument lines—termed Speedomax "Type H" controllers and "Series 60" Proportional-Control Units—are announced by Leeds & Northrup Co., Philadelphia. Both are mounted in the Speedomax case when the equipment is to be used for proportional control. The Control unit is also made as a separate instrument for use with the Company's Speedomax Type G and Micromax controllers.

Speedomax Type H Instruments

L&N describes these as compact new Controllers, Recorders or Indicators, and companions to the larger, more versatile Speedomax Type G introduced in 1946. Somewhat less than half the size of the G, they are offered to meet the needs of "many present users of high-grade electronic instruments, as well as of many who haven't formerly been able to justify such instrumentation."

Type H Speedomax is made in single-point only, and at present only for temperatures, with thermocouple or "Thermohm" resistance thermometer as the sensing element. The instruments are said to have relatively long measuring scales and, like all L&N instruments, they employ the full length in setting the control point; which is said to facilitate close control.

Structurally, the instrument is entirely new. Convenience features stressed by L&N include the chart feed, pen, and control-setters, and the location of terminals for thermocouples, etc., in a recess on the outside back of the instrument, for convenient installation and the protection of the instrument tubes, wiring and mechanism.

Series 60 Control Unit

This instrument functions "between" the Speedomax controller proper and the fuel valve or contactor in a proportional control system. Its job is to translate Speedomax measurements into the correct regulating operations. It is made in three types, and L&N says that one or another will meet the needs of any controllable process.

The types are Position-Adjusting Type or Duration-Adjusting Type (PAT or DAT) with what instrument men call proportional, reset and rate actions; and simple Proportional Control.

Series 60 replaces the Company's Series 50, introduced in 1949. It measures 11″ × 6½″ × 11″, or about half the panel space of the earlier Unit. It features greater simplicity, interchangeability of PAT, DAT and Proportional units, plug-in construction, and the advances in sensitivity, speed and flexibility which many processes can use today and which more will require in the near future.

New Sealed-Beam Headlamp for Safer Night Driving.—A new type of Sealed Beam headlamp, designed to make night driving easier and safer, has been unveiled by the Automobile Manufacturers Association. The improved design is the product of a four-year cooperative engineering effort by U. S. motor vehicle and headlamp manufacturers, working closely with public officials in the states and the provinces of Canada. A similar program produced the present Sealed Beam design introduced in 1939.

Development and testing work has been completed and the new lamp now is ready for production. It is completely interchangeable with Sealed Beam lamps presently in use, and will be adopted as standard equipment by all motor vehicle manufacturers in the U. S. and Canada during the 1955 model year, the AMA said.

These major improvements are incorporated in the new design:

1. Better distribution of light on the roadway. The lower beam is most no-

ticeably improved, giving as much as 80 ft. more seeing distance along the right side and shoulder of the road.

2. A sharp reduction in stray light radiating upward from the lower beam filament. This change greatly improves night seeing ability in fog, rain, or other adverse weather conditions, and lessens the possibility of glare.

3. More light throughout both beam patterns.

Lighting engineers demonstrating the new design stressed the importance of headlamp aiming. For the motorist to enjoy the maximum advantages of lamp design, whether it be the old or the new Sealed Beam type, he must make sure the aim is right and that lenses are clean, the engineers declared. Headlamp aim, they said, should be checked periodically as a part of regular vehicle maintenance.

Development of the improved lamp grew from the fact that night driving conditions have changed significantly during the past 15 years, the AMA said. The number of motor vehicles in the U. S. has doubled since World War II. As a result, the average driver at night must keep his headlights depressed for oncoming vehicles much more of the time than was the case when the present type of Sealed Beam lamp was introduced in 1939.

The primary objective of the cooperative industry headlamp improvement program, therefore, was to increase the seeing distances provided by the lower beam.

Before the new lamps may be installed on new motor vehicles as original equipment, restrictive statutes in some states must be changed, the AMA reported. These statutes, which govern the type of lighting equipment that may be installed on motor vehicles, are applicable to the present Sealed Beam specifications. The new lamps, therefore, would be in technical violation of some of these statutes.

To legalize use of the new lamps, 22 jurisdictions must pass corrective legislation in 1955. Vehicle manufacturers, the AMA said, are hoping to be able to start factory installation of the lamps by mid-year.

Plastic Assault Boat to Be Tested. —Wide beam 16-ft. fiber glass plastic "assault boats" weighing less than 300 lb. are now being produced by Universal Moulded Products Corporation of Bristol, Va., for service testing by the Army Corps of Engineers. Engineering tests on plastic boats have already been successfully completed by the Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

Designed for assault crossings of rivers and streams, the boats to be service tested are strong enough to carry 15 men with full packs, yet light enough to be readily hand carried. They are laminated under 65-lb. pressure by use of a light gauge, inexpensive steel mould and a preformed rubber blanket which serves to provide the vacuum pressure prior to the application of additional pressure and heat to the laminate in a large autoclave.

The purpose of the additional autoclave pressure is a thorough "wetting out" of the glass fibers by the resin, which in turn guarantees uniformity in mass production. For quick detection of "starved areas" which sometimes occur in plastic laminates, these boats are not pigmented or painted prior to inspection by the Engineers.

Boats laminated by this close quality control process are expected to be competitive with boats produced by other techniques.

The successful performance of these "assault boats" in forthcoming tests may contribute materially to the military's adopting fiber glass plastics for the construction of many small landing craft.

New Multi-Crystal Ultrasonic Generator.—A new high-powered multi-crystal ultrasonic generator which will make possible the construction of larger and more flexible industrial cleaning equipment has been announced by the Specialty Control Department of the General Electric Company.

The concept of cleaning with high-frequency sound waves has found wide application in industry during the past few years through the use of self-contained, single-unit ultrasonic generators. G. E.'s new generator is larger and more powerful, consisting of two separate units. According to G. E. engineers, this makes it possible to design ultrasonic cleaning tanks which can take larger parts, or which can be used for mass-production, continuous-process cleaning of small parts.

The two units of the new multi-crystal ultrasonic generator are the power oscillator, which is enclosed in a separate cabinet, and the transducer assembly which contains five quartz vibrating crystals and can be remotely located from the oscillator.

The transducers are hermetically sealed so they can be placed directly into a tank of solvent. This, with the flexibility achieved with remote location, allows the new G-E generator to be easily incorporated into a regular vapor-degreasing or hot-dip process.

The equipment is also designed so that four transducers may be used with a single power oscillating unit, bringing vastly increased power to a single cleaning installation.

High-powered ultrasonic generators can affect industrial cleaning processes in two major areas, according to G-E engineers. They can speed up normal cleaning operations by as much as 100 times, or they can make possible the effective cleaning of parts which are inaccessible to brushes or other cleaning methods.

New Record for High Altitude Parachute Jumps.—A new record for high altitude parachute jumps has been set by two U. S. Air Force officers who parachuted safely from a B-47 at 45,200 ft., the Air Force disclosed recently. The record jumps, which were made by Captain Edward G. Sperry and 1st Lieut Henry P. Nielsen over the Gulf of Mexico, utilized new type downward ejection seats being tested by the Wright Air Development Center, a part of the Air Research and Development Command. A stripped-down Boeing B-47 was modified for the tests.

Lt. Nielsen, of Staten Island, New York, made the first jump on August 2, and Captain Sperry, of Tacoma, Washington, made his jump the following day. The temperature at 45,200 ft., at time of bail-out was 37° below zero Centigrade. The old parachute record of 42,000 ft. was set in August 1950 by Major Vincent Mazza of the Wright Air Development Center.

The tested method of emergency escape from high speed aircraft utilized an ejection seat mounted on rails which is driven downward and out of the aircraft by the explosion of a powder cartridge. The fully automatic system releases the jumper from the seat and opens his parachute by special explosive and timing devices.

Lysergic Acid Synthesized.—A team of scientists in the organic chemistry division of Eli Lilly and Company, Indianapolis pharmaceutical manufacturer, has synthesized lysergic acid, a basic compound in the structure of ergot alkaloids which have broad uses in medicine. Chemists have been trying to do this for at least thirty-six years. The lysergic acid synthesis is regarded by scientists as a major contribution to organic and pharmaceuti-

cal chemistry, comparable to the synthesizing of morphine, quinine, or strychnine—all "classical" problems which for many years defied the best efforts of organic chemists.

Important to medicine because of their wide range of physiological action, the ergot alkaloids include ergonovine, which is widely used in obstetrics to stop postpartum hemorrhaging. Steps already are known by which lysergic acid can be converted to ergonovine, so that the Lilly discovery also constitutes the first total synthesis of this important drug.

The dihydro-ergot alkaloids have been used in the treatment of high blood pressure. Ergotamine, a complex derivative of lysergic acid, is useful in the symptomatic treatment of migraine headache. Recently lysergic acid diethylamide (LSD) has been discovered to be a useful tool in mental disease. Given to normal persons, LSD causes temporary symptoms of schizophrenia, a type of psychosis characterized by withdrawal from reality into phantasies and by disintegration of personality.

The Lilly chemists already have prepared a number of new synthetic derivatives of lysergic acid, with some demonstrating "very interesting" pharmacological activity. The possibility of new medicines being discovered in this field has been increased by the Lilly discovery.

In a statement, Eugene N. Beesley, president of Eli Lilly and Company, said:

"This success of our organic chemists has very practical value. Ergot is expensive and at times extremely scarce. At the present time it takes about 1,000 pounds of ergot to yield 1 ounce to 1½ ounces of ergonovine. In the last decade the price of ergonovine has fluctuated around $60,000 a pound and has been as high as $100,000 a pound.

"Although monumental problems are involved, we are hopeful that our chemists and chemical development will be able to translate the laboratory findings into a process for large-scale manufacture, thus assuring a plentiful supply for the use of the medical profession."

Solar Energy for Arid Regions.—Solar energy will serve the world when coal and gas run out, but it will be of value today and tomorrow in areas without easily available industrial fuel, Prof. Farrington Daniels of the University of Wisconsin recently told scientists in New Delhi, India. Prof. Daniels is chairman of the Wisconsin chemistry department and an expert on atomic and solar energy. He spoke to those attending a conference on wind and solar energy sponsored by the Indian government and the United Nations.

"Our rapidly increasing population and our still more rapidly increasing demands for industrial energy may well bring on a crisis of insufficient fuel for the world much sooner than we now anticipate," Daniels said. He pointed out that if gasoline or other fuel must be transported by camel it is essentially unavailable for any large-scale enterprise.

"For the sake of those people who live in arid regions where sun and land are abundant and fuel is prohibitively high, we should try vigorously to find new energy at once," he said.

At the present time solar engines are so inefficient as to be economically sound only where fuel-powered engines cannot be used, he said. Solar engines that are cheap and simple would undoubtedly find wide use in areas where they provide the only power available. Such engines would convert into useful work some one to five per cent of the sun's radiation.

Scientists working on solar engines should keep in mind that the problem

is not to develop a device with high efficiency—but to develop the most horsepower or the most kilowatts for a given investment of capital and a given burden of transportation, Daniels said.

"Even if the solar engine is only one per cent efficient, a thousand square feet of sunshine would give one horsepower," he added. "This area is not much larger than that needed for a horse walking around a well from which water is being raised—and then the good agricultural land needed for feeding the horse would become available for feeding the animal's keeper and his family."

New L & N Gas-Fired Homocarb.—At the American Society for Metals Exposition in Chicago, Leeds & Northrup announced the extension of their Homocarb furnace line to include a gas-fired model, made in eight sizes, with work spaces from 15 in. × 18 in. to 25 in. × 48 in. The furnaces are vertical, batch type units, identical with other Homocarb furnaces except for method of firing. The burners are tangential to the combustion chamber; number of burners depends on furnace size. Burners are luminous-flame type, and the use of these burners, with regulation by Duration-Adjusting Type (DAT) temperature control, produces a long flame which wraps around the furnace retort. The retort thus becomes a single radiant tube, supplying a uniform wall of heat around the work chamber.

Equipment includes a Safe-Start burner control unit, with all gas and air valves, safety interlocks, blower and other accessories. Microcarb control is provided for continuous, automatic regulation of the carbon content of the furnace atmosphere. Announced applications of the furnace include carburizing, carbon restoration, hardening, or homogeneous carburizing cycles. Equipments are said to be promptly available.

Chromium Plated Engine Cylinder Walls.—More than $15,000,000 has been saved in the cost of aircraft engine cylinder walls since the Navy adopted a process of chromium plating the walls of engine cylinders to extend their service life. The process has extended the service life of engine cylinders from 1200 to more than 3,000 hours of operation. By eliminating corrosion of the cylinder bores, the coating reduces by 50 per cent the wear on pistons and rings, oil consumption, and accumulation of carbon and sludge in oil systems. The process was initiated at the Naval Air Station, Pensacola, Florida.

Metallic Plastic Pipe Patch.—The Navy recently adopted a new plastic patch that has partially solved the problem of emergency repair of ruptured or damaged piping aboard ship. The plastic patch, which has all the simplicity of a first aid bandage for a wounded man, is easily applied and can, for instance, put a ruptured fire main system, magazine sprinkling, or salt water cooling system back into operation in approximately 30 minutes. Tests so far indicate that metallic plastic pipe patches should be used only on salt or fresh water piping whose pressure does not exceed 300 pounds, or whose temperature is not above 200 degrees Fahrenheit. However, other tests are now being conducted to find methods of applying this plastic patch to lines carrying steam, gasoline, or other material. The metallic plastic patch can be used on most types of ruptures, including a severed section of pipe that has been completely separated, a ruptured elbow, that is located

on any curved section of pipe, a compound rupture with protruding edges, or ruptured in fittings. To apply a patch to a severed or ruptured metallic pipe requires approximately 15 to 20 minutes, and pressure can be restored to the system within 30 minutes after application. Little skill is needed to apply the patch, as the materials, before hardening, are pliable and are easily applied. The maximum patch life is unknown as yet, but experience has shown that a properly applied patch will last until permanent repairs can be made.*

Three-Dimensional Tic-Tac-Toe Game.—Qubic—the new three-dimensional game for two to four players—is stimulating, brain-teasing fun for adults and youngsters alike, making it a good family game, yet equally entertaining in employee recreation rooms. The game is played, with colored disks, on four levels. The top three surfaces are clear plastic, making it possible to see through the levels in all directions. One marker is placed on any square in turn, the object being to get four in a straight line (across, diagonal, etc.) through the Qubic. An incredible number of possible plays makes Qubic interesting. The game has been put on the market by American Homecraft Co., of Chicago.

Rustless Fish Hooks (*White Metal News Letter*, Vol. XIX, No. 3).—Fish hooks that will not rust in either fresh or salt water are proving to be a valuable asset to the angler. These hooks, which are made of special heat-treated nickel that is strong and hard, always stay shiny and never rust-stain lures.

* Details available upon request to *Navy Technical News*, Office of Information, Navy Department, Washington 25, D. C.

High-Perfection Silicon Crystals.—A new level of perfection has been reached in silicon crystals produced in the General Electric Research Laboratory at Schenectady.

Evidence for this perfection is a quantity called "lifetime" by which physicists refer to the length of time that an excess of electrons purposely injected to measure crystal quality takes to disappear. Usually "lifetime" is a few ten thousandths of a second; often considerably less. However, in these new crystals, "lifetime" is in excess of a thousandth of a second.

From a special supply of excellent elemental silicon with a purity measured in parts per million and unavailable in more than laboratory quantities until recently, several research associates in the GE Laboratory's semiconductor section have worked to produce the sizeable superpure crystals that show these highly important qualities.

One of the investigators, Dr. Hubbard Horn, comments that silicon as contained in common sand is one of the most abundant elements in the earth's crust. But in its highly perfect form, as now produced in the Research Laboratory, it is a rare and invaluable semiconductor.

Yet, while GE scientists can achieve unbelievably high purity by ingenious processing, "this still isn't good enough for what we want to do with it," Dr. Horn said, discussing methods by which the present goal was achieved.

It may never be possible to gain absolute purity and perfection in silicon but the attempt will continue; otherwise silicon's physical, chemical, and electrical properties can never be fully known. Here, as elsewhere in the progress of modern solid-state physics, vast unknown areas invite research, holding out possibilities for val-

uable practical developments and new industries. Like the rare element, germanium, silicon is a semiconductor of electricity. This characteristic makes it useful for transistors, those tiny electronic devices that can do so many things vacuum tubes do, such as amplifying weak electrical currents by 100,000 times.

Research indicates that silicon may be a better material than germanium from which to manufacture certain transistors and rectifiers. This is because germanium begins to lose its important transistor qualities whenever the temperature rises much above 200 degrees Fahrenheit. Silicon transistors will work at temperatures exceeding 400° F.

By achieving high purity as measured (in part) by higher and higher resistivity to the passage of electricity, then adding small amounts of impurities measured in parts per million (a process called doping), scientists hope to achieve electronic controls hitherto impossible. High purity and perfection enable a transistor material to conduct electrons with a minimum of capture by imperfections and impurities. This is highly important for transistors as well as for power rectifiers.

Appreciable progress in the concentrated search for purer silicon was made during World War II. Since then, as progress with germanium increased, interest has multiplied. However, the search has been expensive and difficult. GE's contribution in the field is the achievement of the highest perfection thus far for silicon crystals and the measurement of their properties.

"Silicon," says Dr. Horn, "is today in the position germanium occupied about 1948. We don't expect it to replace germanium, but rather to supplement it. Meanwhile, it is hard not to let our enthusiasm run away with us, because pure silicon seems to have so many possibilities."

The "zone melting," or recrystallization method of refining, is a rigidly controlled procedure. It was previously applied to germanium, but is much more difficult when used for silicon.

Current practices of zone melting consist of successive recrystallizations of silicon as an ingot is slowly drawn through a gas-filled quartz tube. Induction coils are wrapped around the outside of the tube, causing the slowly moving ingot to melt in narrow zones. In this way impurities are swept to the end of the bar, leaving behind only that silicon which is of highest quality.

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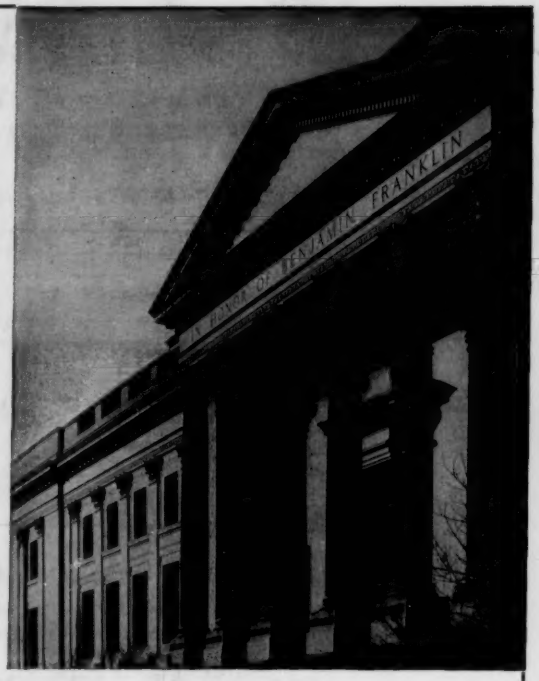

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